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APPENDIX B

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Inward technology transfer as an interactive process

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Abstract

Seaton and Cordey-Hayes [1] have drawn attention to many of the limitations and deficiencies in traditional technology transfer mechanisms. They argued that this was largely due to the dominance of the linear model of innovation on conventional thinking. Furthermore, they presented an alternative model of technology transfer (accessibility–mobility–receptivity) which emphasized the interactive nature of the process and highlighted the absence of any substantial research within the area of receptivity. This paper continues from that 1993 paper and focuses on the concept of 'receptivity' in the context of inward technology transfer.

A conceptual framework is developed which identifies four major components of the inward technology transfer process. These are: 'awareness', 'association', 'assimilation' and 'application'. Using this conceptual device, a series of studies is conducted within a number of businesses within ICI Chemicals and Polymers Ltd.

The conclusions indicate the importance of non-routine activities and effective communications between credible boundary-spanning individuals. These are key aspects of the assimilation of new knowledge and the inward transfer process. This requires successful organizations not only to be efficient and competitive at their routine business in order to survive in the short term, but also to make room for opportunities for these creative, non-routine assimilation processes, which are more stochastic in nature, if they are to remain competitive in the long term.

1. Introduction

A recent study of firms in Sweden, Japan and the United States revealed that the external acquisition of technology was the most prominent technology management issue in multi-technology corporations [2]. The role of traditional R&D management, particularly in Western technology-based companies, has focused on the management of internal R&D. The study suggests that the external acquisition of technology emphasizes increasingly important challenges and new responsibilities for technology managers. Similarly, recent research by Rothwell [3] has highlighted the importance of external networks in facilitating the innovation process. The research revealed that innovative small and medium-sized enterprises (SMEs) have dense external networks in a variety of marketing and manufacturing relationships.

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These linkages are often informal alliances and industry associations. Nonetheless, these networks are often the stage upon which much know-how is exchanged [4, 5]. However, it appears that not all firms have the capacity to forge and develop effective external linkages, formal or informal. Rothwell and Beesley [6] posit that the most significant factor determining an SME's propensity for and ability to access external technology is internal to the firm; most notably "the employment of qualified scientists and engineers (QSE) and the outward-lookingness of managers". In other words, the lack of internal technological know-how can inhibit external know-how accumulation and a firm's receptivity to externally developed technology. In earlier papers, the capability of an organization to engage in knowledge transfer, accumulation and learning has been called receptivity [1] or absorptive capacity [7].

The notion of 'receptivity' advocated by Seaton and Cordey-Hayes [1] suggests that there are certain characteristics whose presence is necessary for inward technology transfer to occur. In a similar vein, but within an R&D context, Cohen and Levinthal [7] put forward the notion of 'absorptive capacity'. In their study of the American manufacturing sector they reconceptualize the traditional role of R&D investment as simply a factor aimed at creating specific innovations. They see R&D expenditure as an investment in an organization's 'absorptive capacity'. They argue that an organization's ability to evaluate and utilize external knowledge is related to its *prior knowledge* and expertise and that this prior knowledge is, in turn, driven by prior R&D investment.

The importance of a strong research and innovation tradition was also highlighted by Freeman [8], who showed the dominant role played by a few leading companies in the world chemical industry over a long period. Freeman suggested that this long period of innovative success was due to 'technological accumulation', and that "such accumulated strength and experience appears to outlive particular individuals". This suggests that it is the organization, rather than the individuals who pass through it, that is responsible for *accumulating and retaining* technical competence. The issue of an organization's capacity to acquire knowledge was addressed by Nelson and Winter [9] who emphasized the importance of 'innovative routines', suggesting a need for some structure. They argue that the practised routines that are built into the organization define a set of actions that the organization is capable of doing confidently. These routines are referred to as an organization's core capabilities. It is important to note that the notion of routines here does not necessarily suggest a mechanistic structure. The point is that, over long periods of time, organizations build up a body of knowledge and skills through experience and learning-by-doing.

Defining precisely what activities are required on the part of the organization and the individuals within it is not explored by any of the above authors. So while there is some conformity on the importance of the accumulation of organizational knowledge and capabilities, there is little written about the processes required by the organization to achieve this desirable state of 'receptivity'. (A similar argument is made by Bessant *et al.* [10] who advocate a need to develop understanding of the routines associated with 'incremental innovation'.) Hence there is a need to uncover the internal organizational processes that contribute to 'receptivity'. A simple conceptual framework is developed that captures the main elements of the inward technology transfer process. This framework will be used to analyse the inward technology transfer process to uncover the activities involved.

2. The external search for technology: a case study of ICI

During 1989 ICI Chemicals & Polymers Ltd (C&P) established a Technology Trawling Group (TTG) to search for technology that the organization could use to build a new business for the C&P group. The process of acquiring externally developed technology, bringing it back into ICI and utilizing the acquired technology proved to be far more complex than was originally envisaged.

It became clear that in order to successfully transfer externally developed technology into an organization it was necessary to understand the process from the viewpont of the 'receiving' organization.

To contribute to this understanding, a series of studies was designed to examine the organizational factors involved in the inward technology transfer process. Our earlier research indicates the inward transfer process could be envisaged as a series of stages, which have been called awareness, association, assimilation and application [11]. The first study aims to uncover the factors involved in awareness and association and the second explores the assimilation process, using cognitive mapping.

The initial investigation set out to uncover information from a variety of people within the organization who had been involved in previous attempts to acquire technology from the TTG. This initial investigation used a semi-structured in-depth interviewing technique. The aim was to get the participants to discuss the general area in their own terms. The following factors were uncovered:

- the technology did not complement existing activities;
- the business possessed insufficient technical knowledge of the new technology;
- the business possessed insufficient commercial expertise in the area where the technology was to be applied;
- the business had previously examined very similar technology;
- the technology did not fit with areas the business was currently trying to exploit;
- the technology did not complement the business's future plans.

The TTG had great difficulty in trying to get the businesses to articulate the technology that would be of interest to them. The typical response was "If we knew what we wanted we would go and get it!".

The businesses were only able to define the *broad* area of interest. Decisions were based on *tacit* knowledge of the business. Individuals within the business were aware of what type of technology was required, what type of technology would work, and they were also aware of the needs of their customers. However, the relevance and importance of each of these issues were held within different parts of the business.

It was also clear that the business did not have technology requirements that could be easily articulated in the form of a simple 'shopping list'. Their technology needs involved a variety of issues. Furthermore, the inward technology transfer process appeared to concern the ability to link technical opportunities with commercial opportunities and match these with internal technical and commercial capabilities. As if this was not enough, it also concerned developing 'interest' and 'enthusiasm' among people within the business to ensure the technology was applied effectively.

ICI C&P and the R&T department in particular absorb vast quantities of information every day. Every scientist, technologist or commercial employee collects and gathers information in a huge 'osmosis process'. This is achieved via a wealth of information sources made available by the organization (see Table 1).

3. The development of the 4A model as a framework for inward technology transfer ('receptivity')

It is argued that inward technology transfer will be successful only if an organization has not only the ability to acquire but also the ability to assimilate and apply ideas, knowledge, devices and artefacts effectively. Organizations will respond to technological opportunity only in terms of their own perceptions of its benefits and costs and in relation to their own needs and to technical, organizational and human resources. The process view of inward technology transfer, therefore, is concerned with creating or raising the capability for innovation. This requires an organization and the individuals within it to have the capability to:

- search and scan for information which is new to the organization (*awareness*);

- recognize the potential benefit of this information by *associating* it with internal organizational needs and capabilities;
- communicate these to and *assimilate* them within the organization; and
- *apply* them for competitive advantage.

These processes are captured in the following stages: awareness; association; assimilation; and application. This four-stage conceptual framework (4A) is developed in [12] and is used to explore the processes involved in inward technology transfer. *Awareness* describes the processes by which an organization scans for and discovers what information on technology is available; *association* describes the processes by which an organization recognizes the value of this technology (ideas) for the organization; *assimilation* describes the processes by which the organization communicates these ideas within the organization and creates genuine business opportunities; and *application* describes the processes by which the organization applies this technology for competitive advantage. The 4A model is a conceptual tool that is used as a way of studying the process of inward technology transfer. The development of the conceptual framework is explained below.

3.1 Awareness — the first stage

It has long been recognized that a key characteristic of technically progressive firms is their high quality of incoming information [13]. Many other studies have since demonstrated the value and importance of external information for successful innovation. For example, SPRU's Project SAPPHO confirmed the need for high-quality external linkages [14–16].

Each organizational research effort or technological activity represents a fraction of the world's total scientific and technological activity. Organizations are constantly surprised by the amount of technology that is around that they do not know about. Hence organizations must somehow ensure their personnel are aware of technological developments done elsewhere. During the 1960s and 1970s this question of how to keep personnel aware of technological developments was the subject of intense study [17–20]. Some interesting and useful concepts were developed that helped to improve our understanding of the complex nature of how individuals within organizations acquire technological information. Recent literature from Japanese management scholars, developing a contemporary frame of reference in firm management, has emphasized the importance of 'tacit knowledge' in the innovation process [21–23].

> *"Tacit knowledge is highly personal. It is hard to formalize and, therefore, difficult to communicate to others. It is deeply rooted in action and is context specific. It is embodied by the term know-how. It is difficult to articulate meaningful know-how in text and figures . . . The knowledge is alive because it changes continuously"* [22].

Scanning by individuals on behalf of the organization is often regarded as an informal and unassigned activity. But in order for individuals to practice the process effectively organizations must recognize the value of the activity. It appears that because organizations are unaware of its value they do not provide the organizational support for the process.

In the 1960s, research at the Massachusetts Institute of Technology developed the notion of the 'gatekeeper'. Allen and Cohen [18] developed the research further by suggesting that 'gatekeepers' were also 'information stars' that possessed a high degree of awareness of the external environment. A criticism of Allen & Cohen's work is that it tends to suggest that organizations should have a number of key scanners who are responsible for the collection of information for the organization. Although gaining information from the external environment for use by the business was often regarded as a senior management activity, evidence suggests that there is no greater overall scanning activity by upper-level management than by middle-level management [24–26].

Given the importance of the need to be aware of external information and the role of technological scanning and networking that appear to enable an organization to access this wealth of potential knowledge, 'awareness' is seen as the necessary first stage in the inward technology transfer process. It is defined as being *informed and vigilant of one's technical and business environment, using a variety of information sources, especially the processes of scanning and networking* (see Fig. 1). Scanning is defined as *purposeful search and undirected viewing, often termed browsing.* It includes informal and formal, structured and unstructured methods of information search. The use of networks or 'networking', as it is often called, is the process of interaction with other people, resulting in the informal trading of knowledge [27]. This includes formal and informal interactions. Hence the development of the following two propositions:

- *[P1] Effective scanning depends on the explicit recognition by the organization of the role of technical and commercial scanning.*
- *[P2] Effective networking depends on the explicit recognition by the organization of the role of networking.*

3.2 Association — the second stage

Many internal organizational needs are not expressed explicitly as a need, but may be more appropriately described as 'opportunities' that exist. Virtually every organization will possess a variety of opportunities; many of these may remain unfulfilled, others will be taken and changes introduced. For example, 'opportunities' often exist to improve a manufacturing process or a product by reducing costs associated with it. These opportunities tend to be needs that are not perceived in technical terms. In a study of small firms, Anstey [28] found that small businesses do not perceive their needs in technological terms. They are often seen purely in financial terms of reducing costs and increasing revenue. As a result, business opportunities are not perceived, and certainly not expressed, by the business as a technology requirement. Hence, such companies would be unlikely to be involved in technology scanning.

In order for an organization to search and scan effectively for technology that will match its business opportunities, it needs to have a thorough understanding of its internal organizational capabilities. It appears that this can be effectively achieved via the processes of internal scanning and networking, which will enable it to become familiar with its internal activities. The coupling of internal technological scanning with external technological scanning activities can be seen in Fig. 1.

Inward technology transfer involves more than identifying interesting technology; it is necessary to match technology with a market need, thus producing a potential opportunity for the business. Hence, the scanning process needs to incorporate commercial scanning as well as technological scanning so that technological opportunities may be matched with market needs (see Fig. 1). The strategic management literature offers much advice on the innovation process, particularly on the need to couple technology with market needs [29–31]. But it fails to say specifically how to do it.

The process described above, and shown in Fig. 1, explains how firms can amass both technological know-how and commercial know-how. However, to exploit technology the firm must have a range of internal business capabilities, part of which includes the appropriate technical skills. Furthermore, it is the assimilation of these potential 'business opportunities' with the organization's capabilities that will create viable business opportunities. Finally, the coordination of these organizational resources is necessary for successful technology transfer and the ultimate production of competitive products [32]. Hence the development of Proposition 3:

- *[P3] A thorough understanding of the business's operations, markets, capabilities and future business plans is essential for effective scanning and networking.*

Many people fail to recognize that using other people's information is much more difficult than using their own [33]. Others have developed their information often over a long period of time, with

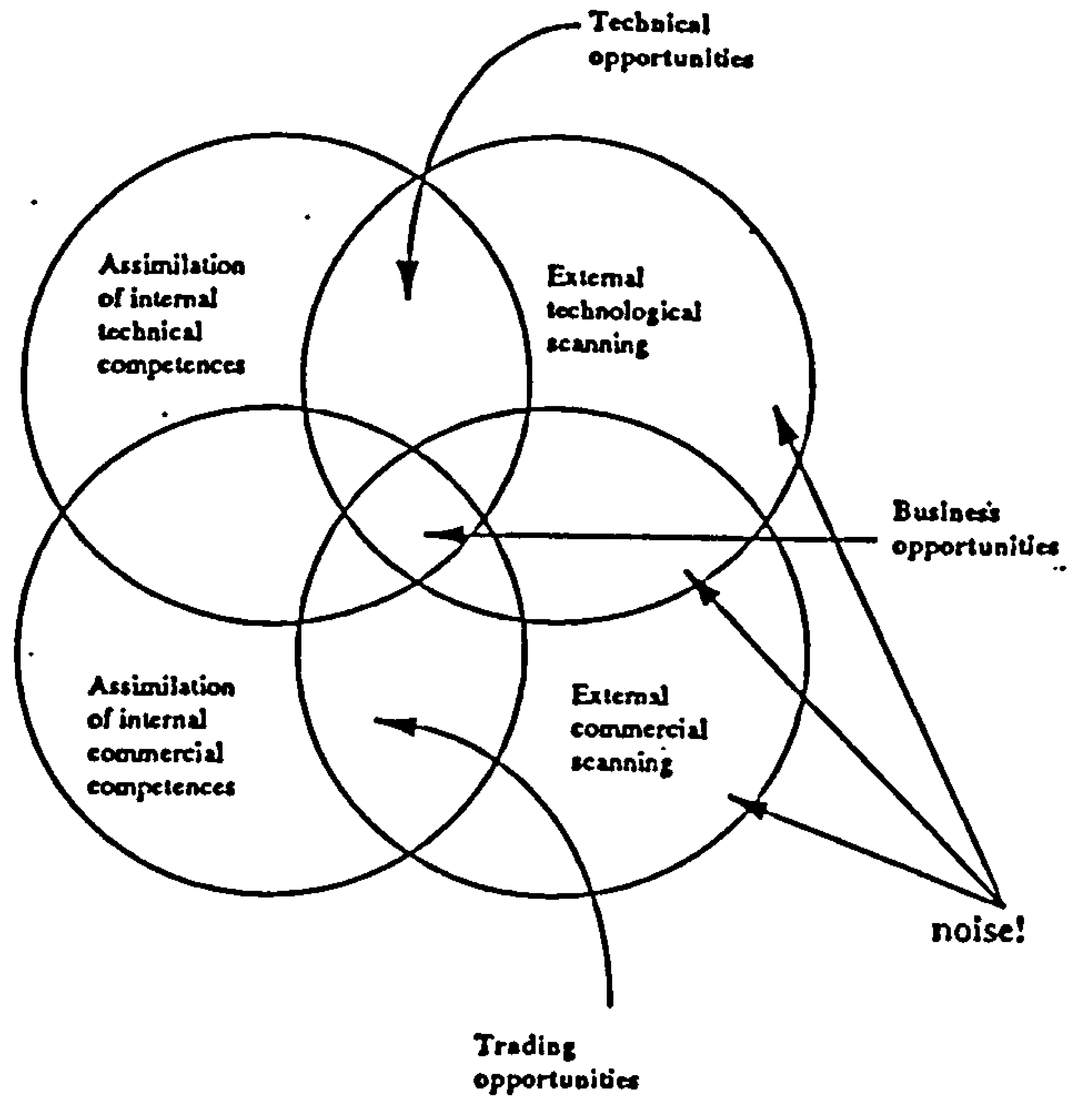

Fig. 1. The awareness and association processes — Tuned scanning and noise! (See [11, 12] for a more detailed explanation of the development of this model.)

the unwitting help of many different people and using organizational routines and techniques that are not easily explained or transferred. Furthermore, much of this information is tacit knowledge. Consequently other people's or firm's technology may not fit the circumstances of another firm. Tushman and Scanlan [34] argue that there is no evidence to suggest that information gathered from external sources is disseminated within the organization.

Technology can be effective only if it is fully integrated into the firm's activities. This can be achieved only if the new technology is aligned with existing competences, both technological [35] and commercial. A study by Adler and Shenhar [36] of two companies in the defence industry suggested that the technological base of the organization incorporates more than just the physical technology and technical skills held within the organization. They argue that it includes four components: technological assets, organizational assets, external assets and projects. This more realistic assessment, by Adler and Shenhar, of an organization's technological base shows how the various components of an organization are interrelated. The inclusion of its external networks is an important point. The formal and informal links an organization has developed, often over many years, are a valuable asset.

The preceding discussion highlighted the importance of maintaining a high degree of awareness of both the internal activities and the external opportunities available to an organization. The inward technology transfer process appears to be dependent on the creation of linkages between internal and external situations and commercial and technical opportunities. This process appears to be made almost exclusively by individuals on behalf of the organization, who are able to combine these linkages [37, 38]. This process of 'association' is seen as the second stage in inward technology transfer.

Beji [39] stresses the importance of accessing external knowledge rather than external information, and warns: "a firm looking for knowledge is likely to encounter all kinds of information in its environment". The concept of signal-to-noise ratio can be usefully applied to the scanning process. External scanning without a full understanding of the organization's capabilities and future requirements is likely to produce much noise along with the signal. Thus 'tuned scanning', via internal assimilation of an organization's activities, as opposed to 'untuned scanning', will produce a higher signal-to-noise ratio.

The complete tuned scanning process (shown diagramatically in Fig. 1) ensures that the scanning activities are tuned into the appropriate needs of the business. This ensures that all identified technology and marketing opportunities are assimilated with existing technical and commercial competences, that is 'organizational capability'. The result is a process that produces a high level of business opportunities for consideration by the business as opposed to 'noise' in the form of information that is inappropriate for consideration by the business. Furthermore, without tuning, the scanning process may consume vast amounts of resources without producing any benefits (see Fig. 1). Hence the development of Proposition 4:

- *[P4] The coupling of internal and external, technical and commercial scanning will produce business 'associations'.*

3.3 Assimilation — the third stage

The next stage of the inward technology transfer process is commonly referred to in the literature as 'adoption' [40, 41] and is dominated by references to 'champions', either product or business. Such key people, it is argued, are required in order to promote the business idea internally and push the idea through to final exploitation. However, it would appear that the so-called process of adoption of technology by the organization is a far more complex process than some writers would have us believe. The role of a champion is only one of many different factors, not least of which is the integration of new technology with the existing knowledge base of the organization. This demonstrates the need to understand the activities undertaken by the organization in learning about the technology and then adopting it. This 'assimilation' stage of the inward technology transfer process will be explored through the use of an interactive modelling technique known as cognitive mapping.

It is important to recognize that the knowledge base of an organization is not simply the sum of the individual knowledge bases. If this were the case, and knowledge were held only at the individual level, then organizations would change simply by employee turnover. The wealth of experience built up by an organization through its operations is clearly not lost when employees leave. The employment of new workers and the retirement of old workers is not equivalent to changing the skills of a firm. There are several tangible representations of this knowledge such as data banks of customers, operating procedures, manufacturing quality control measures, as well as less tangible representations such as tried and tested ways of operating. Nelson and Winter [9] argue that such learning by doing is captured in organizational routines. It is evident that the knowledge base of an organization will be greater, in most cases, than the sum total of the individual knowledge bases within the organization [42]. Recent writers from Japan suggest there is another way to consider organizational knowledge, and this is found most commonly in highly successful Japanese companies. Nonaka [23] explains:

> *"The centre-piece of the Japanese approach is the recognition that creating knowledge is not simply a matter of processing objective information. Rather, it depends on tapping the tacit and often highly subjective insights, intuitions, and hunches of individual employees*

and making those insights available for testing and use by the company as a whole."

The knowledge base of an organization is defined here as *the accumulation of the knowledge bases of all the individuals within an organization together with the social knowledge embedded in relationships between those individuals.* These relationships are often recognized as organizational processes and procedures [23, 43]. The interactions and relationships between individuals may be said to represent a form of 'organizational cement' that performs two functions: firstly, it combines individual knowledge bases into a larger body of knowledge; secondly, it enables individual knowledge bases to be accessed by the organization, effectively via interaction with other individuals.

The final stage in the inward technology transfer process is the application of the business opportunity for competitive advantage. This is the stage where the organization brings about commercial benefit from the technology. This could be in the form of increased sales through the launch of a new or improved product, or through the result of reduced costs.

4. Results from the studies

Two separate studies were undertaken to uncover the factors involved in three of the four stages in the inward technology transfer process. A structured interview technique was used in the first study to examine 'awareness' and 'association'. The first study examined the four propositions presented earlier in Section 3. The second study used an interative modelling technique, known as cognitive mapping, to uncover the activities involved in 'assimilation'.

The findings from the first study confirm the importance of scanning and networking. All the participants expressed the importance of these non-routine activities in providing useful information. Furthermore, the findings revealed that effective scanning and networkng by individuals on behalf of the organization are dependent on the recognition by the organization of the importance of these activities (Propositions 1 and 2). Without the support of the organization, an individual is clearly limited in the extent of activities in which he/she may engage, no matter how well-intentioned. For example, if the organization does not actively encourage its employees to attend conferences and exhibitions, to visit customers and competitors, through the provision of resources and a supportive culture, it is extremely unlikely that these activities will be undertaken.

The variety of information sources made available to the businesses of ICI and the people within those businesses (see Table 1), coupled with the substantial resources provided for scanning activities, is clear evidence of the commitment the company has to ensure its businesses and its people are aware of information that may be useful and potentially valuable. Individuals within both ICI businesses studied[1] spent substantial amounts of time scanning for information, and several research scientists spent the equivalent of one full working day a week.

The provision of extensive library facilities, including the availability of a wide variety of journals, illustrates the organization's recognition of the scanning activity as a *regular consistent activity* rather than an activity that is undertaken occasionally or when a need has been identified. There was also evidence from the findings that ICI provides additional support, in terms of liberal socialization controls and norms of behaviour, for external informal interaction (networking). The study revealed that interactions with people were identified, by both the ICI businesses, as the most useful souce of information above all other sources. This was because of the 'richness' of the information that could be gathered in the form of tacit knowledge. This view is supported by Nonaka [22], who stresses that the creation of new knowledge is dependent on the recognition by the organization of the importance of tapping the 'tacit knowledge' of individual employees.

The study also revealed support for Proposition 3. The respondents from both businesses showed a thorough understanding of the needs and capabili-

TABLE 1 The range of information sources made available by the organization and used by the participants

(i)	Journals	(x)	Social friends
(ii)	Information scientists	(xi)	Meetings/visits with/to customers
(iii)	On-line external databases	(xii)	Academic contacts
(iv)	Browsing in the library	(xiii)	Trade associations/competitors
(v)	Conferences & exhibitions	(xiv)	Competitor analysis
(vi)	Company accounts	(xv)	Meetings with suppliers
(vii)	Visits to other chemical companies	(xvi)	Consultants/Consultants' reports
(viii)	Internal meetings	(xvii)	ICI Patent department
(ix)	Internal business reports	(xviii)	Government departments

ties of their business. This was fostered through the use of a matrix organizational structure and the use of business teams. These facilitated additional lines of communication within the organization, which enhanced internal awareness of the business's activities (Proposition 3). This framework has led to a style of management that emphasizes information communication and provides a great deal of freedom and autonomy for individuals. This, in turn, demands a high level of mutual confidence and respect from everyone involved in order to ensure the organization functions effectively. (It has also previously been described as 'fuzzy' [44].) Hence there is evidence that ICI recognizes the importance of ensuring its individual employees are aware of the internal needs and capabilities of their businesses. In particular it recognizes the importance of internal informal interaction (networking) and supports the process through the provision of the following:

- an 'open' and informal style of management;
- a matrix organizational form;
- business teams.

Collectively, these three factors provide an environment that values information as a commodity and facilitates the development of a high level of internal awareness of the business's capabilities, activities and future plans. Hence, there is support for Proposition 3 and the overall theory on networking.

The quantitative and qualitative analysis of the data[2] revealed few discernible differences in the *extent* of scanning and networking undertaken by the two businesses. There was, however, a noticeable contrast in the *type* of scanning and networking activities. The analysis revealed an even distribution of commercial and technical scanning within ICIw and a concentration of commercial scanning within ICIs, thereby revealing that the ICIs business undertakes very little technology scanning and networking; hence, the opportunities generated are in the form of 'trading associations' (commercial opportunities), and consequently there are few genuine 'business associations' created. The ICIw business, however, undertakes a range of technical and commercial scanning and networking activities which tend to generate genuine business opportunities. This is confirmed in the histogram in Fig. 2, which shows that considerably more genuine business associations have been created by the ICIw business than by the ICIs business as a result of its scanning and networking activities.

4.1 Uncovering the process of assimilation

Cognitive mapping was used in an attempt to uncover the internal activities involved in assimilation as perceived by the individuals within the organization. Ackerman, Cropper and Eden [45] describe cognitive mapping as a modelling technique which intends to portray ideas, beliefs, values and attitudes and their relationship to one another in a form which is amenable to study and analysis. In order to uncover an individual's mental map the research has to develop a good relationship with the client under study. This will help to

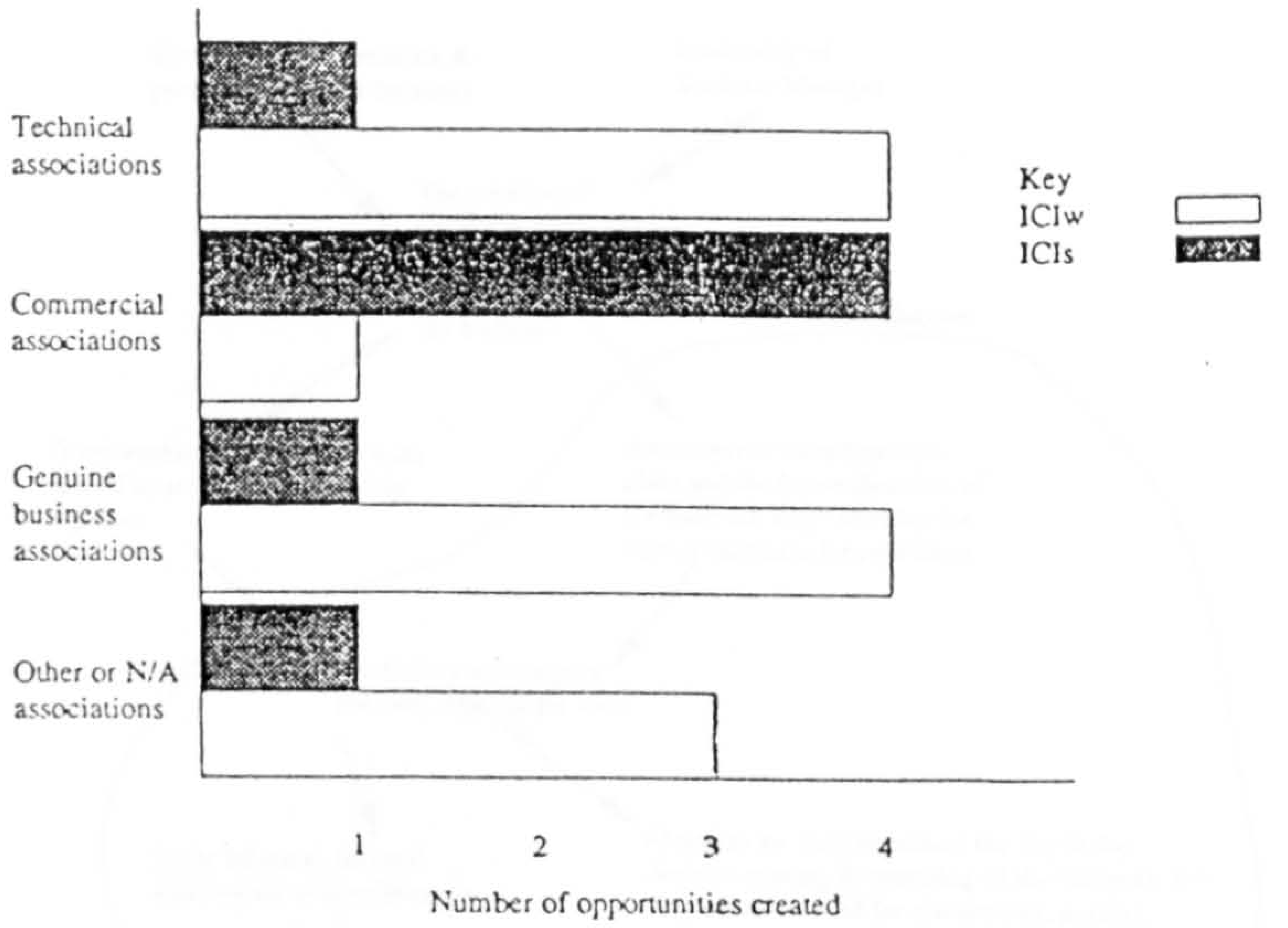

Fig. 2. Summary of the outcomes produced through scanning and networking.

ensure that his client discusses openly and freely the area under study and will enable the client to access theories and perceptions which have been developed through experience.

The interview was designed to encourage the participant to talk about and describe how technical and commercial ideas are transformed into genuine business opportunities. This area was explored in further detail by focusing on the internal factors that affect the transfer of knowledge and ideas. Participants were also encouraged to talk about the internal issues that affect acceptance of technical or commercial ideas. The time of the interviews varied between one and one and a half hours. Each interview was recorded onto audio cassette and, in addition, notes were transcribed during the discussion. The recording of the interview enabled the researcher to capture and place all elements of the discussion. This was transferred verbatim onto a computer software drawing package, and assembled in the form of a cognitive map.

As regards validity, the data collected and produced from cognitive mapping was validated in two ways. Firstly, returning the maps to the participants for comment served as a check that the map was a true and fair representation of their understanding of the process of 'assimilation'. The second validity test involved presenting the maps to senior managers from each of the two organizations. In the case of the two ICI businesses, two senior managers with over *sixty* [sic] years of experience between them at various levels within ICI reviewed all twelve ICI maps. They immediately recognized the organization and believed that the maps captured the activities and processes that exist within the organization. The diagram in Fig. 3 represents an aggregate cognitive map derived from eight indiviudal maps. This illustrates the common core and non-core themes.

The core activities are those which had a high level of influence within an individual's cognitive map. Four common themes were identified as: credibility and respect for colleagues; extensive informal interactions; extensive formal interactions; and awareness of main aims and future direction of business. These themes are integrated and should not be viewed in isolation. They were

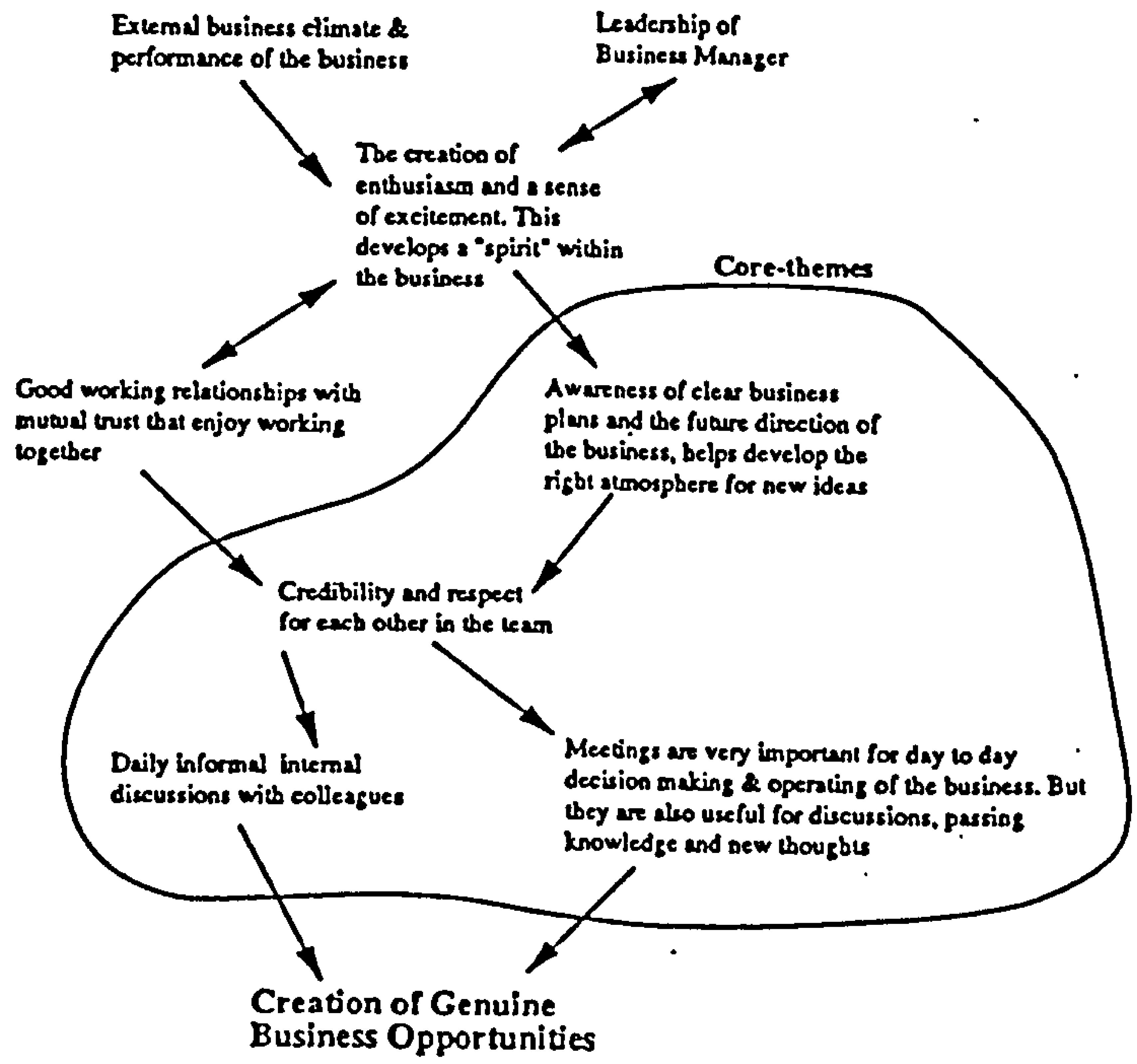

Fig. 3. An aggregate cognitive map from eight individual maps of the *process* of 'assimilation' at ICI. This illustrates the common core and non-core themes.

presented by individuals operating within the organization, in the form of their model of the process of 'assimilation'. As such they are completely interrelated, influencing and influenced by each other, as can be seen from the cognitive map in Fig. 3. They represent the key internal organizational mechanisms in the assimilation of externally developed technology into genuine business opportunities, and will be discussed collectively.

The notion of mutual credibility and respect for colleagues suggests a recognition of the value of the views and knowledge held by colleagues. Indeed, a number of participants maintained that "there is always an expert somewhere in ICI" and "a lot of ideas come from discussions; we rely on our colleagues". Trott [12] has shown that ICI has built a reputation for recruiting high-quality staff. The credibility and respect for colleagues derives from a history of using knowledge effectively, which is made up of a combination of elements. These are:

- experience of individual;
- level of awareness of individual;
- education of individual;
- past performance of individual.

This 'prior knowledge' base of individuals represents an important input into the 'assimilation' process. Cohen and Levinthal [7] argue that prior related knowledge at the individual level provides an ability to recognize the value of new information. This facilitates the creation of linkages and associations that have not been made before. At the organizational level the creation of novel linkages by the individuals is enhanced through communication amongst individuals with diverse and different knowledge structures. Thus prior related knowledge enables an organization to recognize the value of new information, capture it and apply it to commercial ends.

The implication of this ability to create linkages and associations assumes an understanding of the needs of the business. This introduces another core theme. An understanding of the future direction of the business was cited as necessary for individuals to assess whether technical opportunities would be of interest to the business (Proposition 3). Rather than a detailed breakdown of the aims and objectives of the business strategy, the participants within the two ICI businesses sought generalized business objectives. These provide them with sufficient scope to identify potentially useful technical linkages and associations. This finding is consistent with several recent pieces of research within Japanese companies [21–23, 46].

Prior knowledge, however, that is wrapped up and inaccessible is of limited use to the organization. Hence the importance placed on interaction (both formal and informal) within the cognitive maps. There is a substantial amount of research which stresses the need for a 'shared language' within organizations to facilitate internal communication [18–20]. The arguments are presented along the following lines: if all actors in the organization share the same specialized language, they will be effective in their communication. Hence, there needs to be an overlap of knowledge in order for communication to occur. Such arguments have led to developments in cross-function interfaces, for example between R&D, design, manufacturing and marketing. Concurrent engineering is an extension of this. Such thinking is captured in a model of innovation by Bush and Frohman [47]. They argue that the 'up–down' flow of communication in a traditional organization hierarchy blocks innovation and change. They propose a networking structure that allows lateral communication, helping managers and their staff unleash creativity. This model emphasizes the importance of informal networking, across all functions.

4.2 Four common themes

Outside the core boundaries, four common themes were found to be present on the cognitive maps. These factors were identified as necessary ingredients in facilitating the 'assimilation' of technical linkages and associations into genuine business opportunities. They are as follows.

4.2.1 *External operating climate and performance of the business*

It is inevitable that if a business is operating within an expanding and growing market, the operating conditions for that business will be more favourable than if a business is operating in a declining market. Within the businesses studied, individuals recognized that the current performance of the business had a significant influence on the internal 'climate'. Falling sales immediately led to questions about future security and health of the business, whereas rising sales tended to induce a sense of optimism and even excitement at the prospect of new research projects being undertaken. The presence of such influences clearly has an impact on other factors such as the leadership of the business and morale amongst the business teams. These factors are discussed below.

4.2.2 *'Happy teams'*

The previous section emphasized how the assimilation of technical linkages and associations is characterized by extensive regular informal and formal daily interactions. Hence, it is essential that people develop good working relationships. The notion of 'happy teams' tends to induce good teamwork. This emphasizes how individuals are dependent on the performance of their colleagues and a competent team. Good working relationships help to foster mutual respect and credibility, a key component of the core themes.

4.2.3 *Business leadership*

The leadership and managerial style of the business manager was also identified as a significant influence on the way in which the business operates and the style in which it operates. This influence dictated whether there was an emphasis on formal or informal activities and dictated the future direction of the business, especially regarding markets to enter or pull out from. In addition, the type and style of relationship the business manager has with other corporate ICI managers also play a part in determining the 'drive' and 'spirit' within the business.

4.2.4 A 'spirit' and a sense of excitement within the business

This particular factor proved to be difficult to delineate and define. When questioned in more detail about it, participants had difficulty in articulating what they understood by 'spirit'; they found it easier to provide examples: "a buzz in the office that is not present in other businesses I have worked in"; "everyone is enthusiastic and everyone seems to work late"; "we seem to have new ideas to discuss every day"; etc.

It concerns enthusiasm and excitement and appears to be closely related to company culture. Furthermore, it appears to be an effect of the presence of the other three factors: positive operating environment; business leadership; and 'happy teams'. In this context 'spirit' is defined as *dynamism and enterprise, leading to a willingness to explore and a willingness to learn.*

5. Towards a process model of inward technology transfer

It is important to understand that the 4A framework for inward technology transfer is not a formal operational model of inward technology transfer in the traditional sense, but functions rather as a conceptual framework or a vantage point from which to explore the issues involved.

The conceptual scanning framework, developed in Section 3 and shown schematically in Fig. 1, suggests that a range of scanning activities is necessary in order to facilitate the creation of linkages and associations that had not been made before (associations), which the business could subsequently assimilate into genuine business opportunities. It would appear that the absence of one or more of the four scanning activities — (1) internal technical scanning; (2) external technical scanning; (3) internal commercial scanning; (4) external commercial scanning — reduces the effectiveness of the overall scanning process. The internal technical and commercial scanning activities improve awareness and understanding of the business's technical and commercial capabilities and needs. This understanding is used to 'tune' the external scanning or search process. In addition the findings, presented in Fig. 2, showed how the absence of either external commercial or external technical scanning would lead to the creation of mainly technical or trading associations respectively.

The findings from the first study help to characterize the notion of prior knowledge by showing how the provision of an 'information-rich' environment and the recruitment of high-quality staff by an organization facilitate the development of an organization's 'receptivity' to externally developed technology. These points will now be explored.

For many years it has been a policy within ICI to recruit only the best graduates [48]. This study has revealed the importance of two specific, informal, non-routine activities that were undertaken by individuals on behalf of the organization; these were 'scanning' and 'networking' and were used to 'top up' the individual's level of awareness and knowledge. This information was subsequently brought back into the organization for dissemination and to update its knowledge base. The non-routine activities, discussed above, characterize an internal knowledge accumulation process. This is represented diagrammatically in Fig. 4.

While the creation of novel linkages and associations is a necessary part of the inward technology transfer process it is, however, insufficient. These associations have to be applied for competitive advantage in order for technology transfer to be effective. Hence, the organization has to assimilate these associations into genuine business opportunities that it has an intention to exploit.

The findings from the second study are presented in the form of a model of 'assimilation'. An

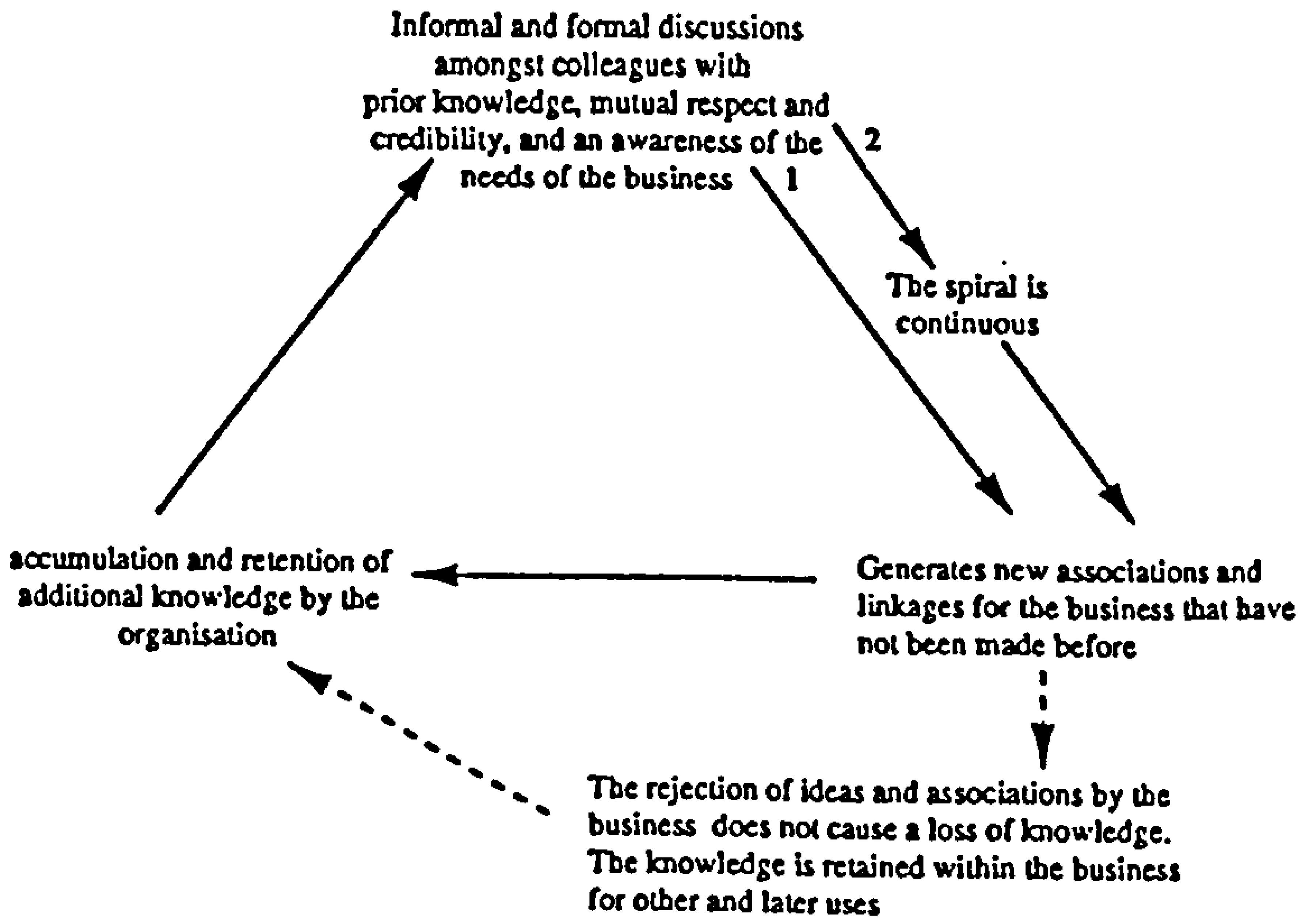

Fig. 4. The internal knowledge accumulation process.

extensive series of complex sequences is revealed as necessary for the assimilation of linkages and associations into genuine business opportunities. It is the sequence of these mechanisms that makes up the process model of assimilation. This model reinforces the importance of Cohen and Levinthal's [7] notion of prior related knowledge and contributes to it by characterizing the notion of 'absorptive capacity'. Several other internal factors are uncovered whose presence influences the process of assimilation. These are 'credibility and respect', extensive 'informal and formal communication', and 'a spirit within the business'.

The model relies heavily on the notion of mutual credibility and respect for colleagues. This notion builds on the evidence presented in the first study which showed that ICI has built a reputation for recruiting high-quality staff and has a history of using knowledge effectively. The findings also revealed that knowledge that is 'wrapped up' and inaccessible is of limited use to the organization. Hence the importance placed on interaction. The second study revealed how, during these interactions, potential ideas, views and opinions are exchanged. The objective is to acquire additional business-specific information and knowledge about commercial and technical associations. Furthermore, the combination of a matrix structure and the use of business teams ensures there is extensive lateral communication between functions. Finally, a number of common themes were revealed whose combined presence appeared to manifest itself in the form of a 'spirit'.

Figure 5 portrays the relationship between the factors uncovered in each separate phase of research. The complexity of the process model may help to explain why inward technology transfer in general and 'assimilation' in particular are so difficult to achieve; a wide range of activities needs to be in place in order for the process to occur. The diagram shows the dynamic nature of the internal activities which is typified by the interrelatedness of all the internal organizational mechanisms.

This model of inward technology transfer has developed the Seaton and Cordey-Hayes [1] theory on receptivity by characterizing the inward technology transfer process. It has demonstrated how

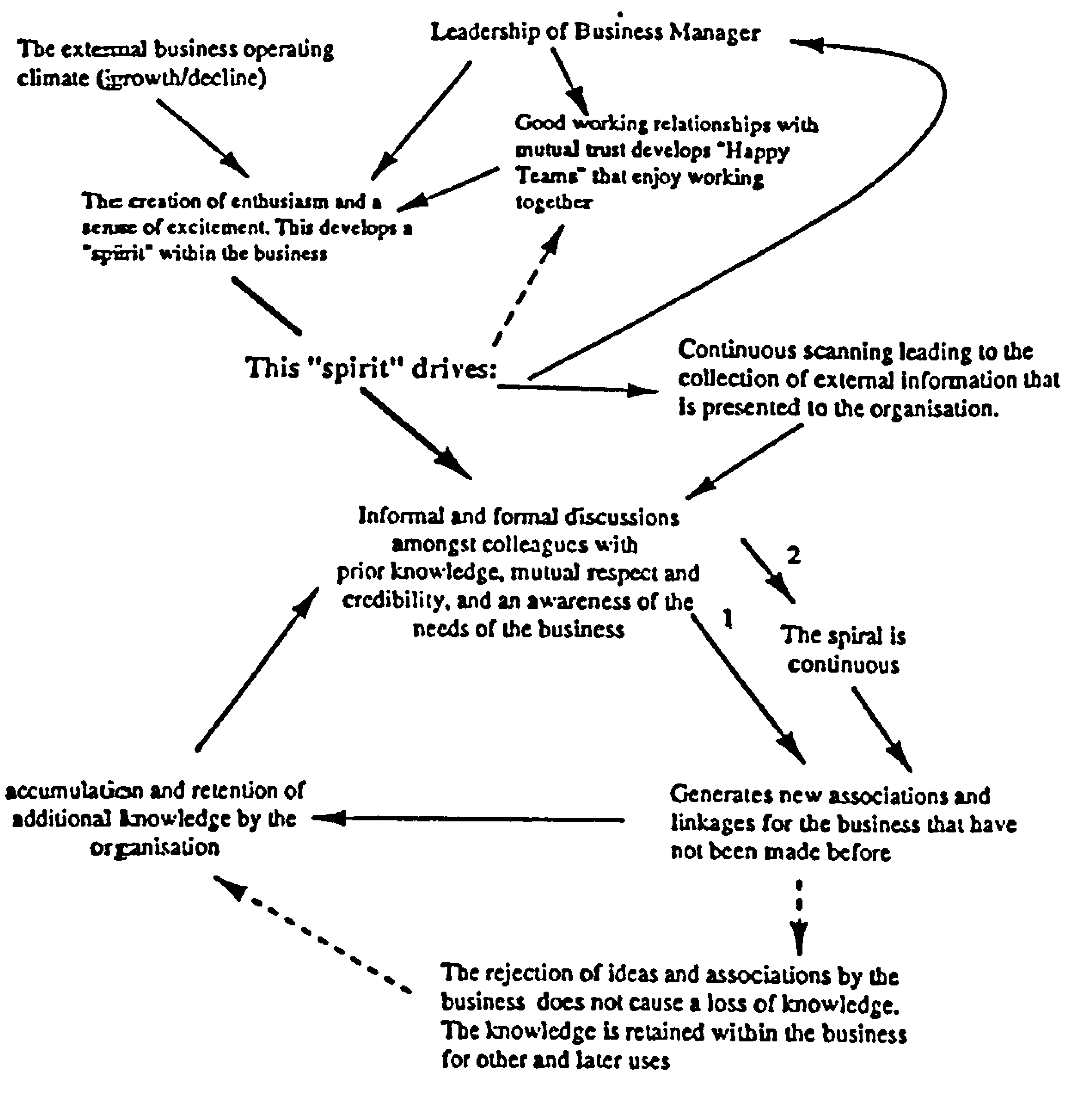

Fig. 5. Model showing the internal factors that affect an organization's ability to engage in inward technology transfer.

the internal activities of scanning and networking affect an organization's awareness of externally developed technology. Furthermore, it shows how a combination of credibility and respect, coupled with extensive informal and formal communications amongst individuals within the organization, facilitates an internal knowledge accumulation process. The model offers an improved understanding of how the internal processes affect an organization's ability to engage in inward technology transfer ('receptivity').

The preceding discussions and model of the inward technology transfer process have shown that the existence of a blend of certain organizational characteristics and non-routine activities is a necessary requirement in determining a business's receptivity to externally developed technology. The ability to accommodate and support such a variety of activities demands careful and skilful management of a business's internal environment. This will now be discussed further.

6. Characterizing the organizational management and organizational environment necessary for inward technology transfer

The findings from the two ICI businesses[1] used in this research project highlight the importance of understanding not only the organizational environment but also the organizational management style.

Two very different business environments were uncovered from the findings of this piece of research. Despite their operating within the same overall organizational structure, that of ICI, the organizational environment of the ICIs business was less able to accommodate the existence of non-routine activities than the ICIw business. An analysis of the history of the businesses can partly explain this difference. The ICIs business is a mature business which has to maintain existing production plants, ensure delivery of products and generally look after existing business activities. Its main concern is to compete with rivals in established markets, which requires efficient performance of routine day-to-day tasks. Maximum efficiency in routine or repetitive activities is achieved by using conservative approaches that emphasize structure and certainty, within a business environment that fosters such order and predictability. The constant manufacture, sale and distribution of products into the market place is a complex process that requires a wide variety of specialist activities. Over the past *one hundred years* the business has established many routines and procedures to ensure this smooth and successful delivery. This has resulted in an accumulation of expertise and specialization within virtually every function.

The environment within the ICIw business is very different. It is a new, growing business with very few established routines and specialized functions. Moreover, it does not have to maintain any plant or to service an existing customer base. Consequently the culture is very different to that of the ICIs business. It is characterized by entrepreneurial behaviour (risk taking, proactivity) within an organic, organizational environment which supports and nurtures that behaviour. Such environments permit rapid response to market and industry demands and changes. Individuals within the ICIw business are more able to engage in non-routine activities, such as scanning and networking, because the business is young and has yet to develop its own routines. This encourages the development of new ideas for the business. Moreover, due to its lack of routinization, it has increased flexibility. Such an operating environment *supports* the non-routine activities necessary to develop new products and find new markets. However, this organic operating environment is not, paradoxically, without its problems. The absence of any routines will produce difficulties and potential problems for the business as it attempts to apply genuine business opportunities for competitive advantage.

It is possible to portray the relationship between the type of organizational management and the type of organizational environment on a graph (Fig. 6). The vertical axis shows organizational environment and the horizontal axis shows the type of organizational management.

There is clearly a 'tension' between the need for organizational routines necessary for the efficient manufacture, marketing and distribution of products and the need for non-routine activities necessary to develop new linkages and associations leading to new business opportunities (see Fig. 6). The existence of this tension appears to be necessary if a firm is to be successful in becoming 'aware' of new information, if it is to succeed in creating new linkages and 'associations' that have not been made before, and if it is to be successful in 'assimilating' these and 'applying' them to commercial ends.

The different organizational characteristics, shown in Fig. 6, that are required for different stages of the inward technology transfer process offer further insight into the extensive range of organizational capabilities necessary in order to participate in inward technology transfer. This research has shown the importance of the presence of a combination of 'stochastic' and 'cartesian' behaviours within an organization. The effective management of a range of such behaviours will enable organizations to recognize the value of new, external information, assimilate it *and* apply it to commercial ends.

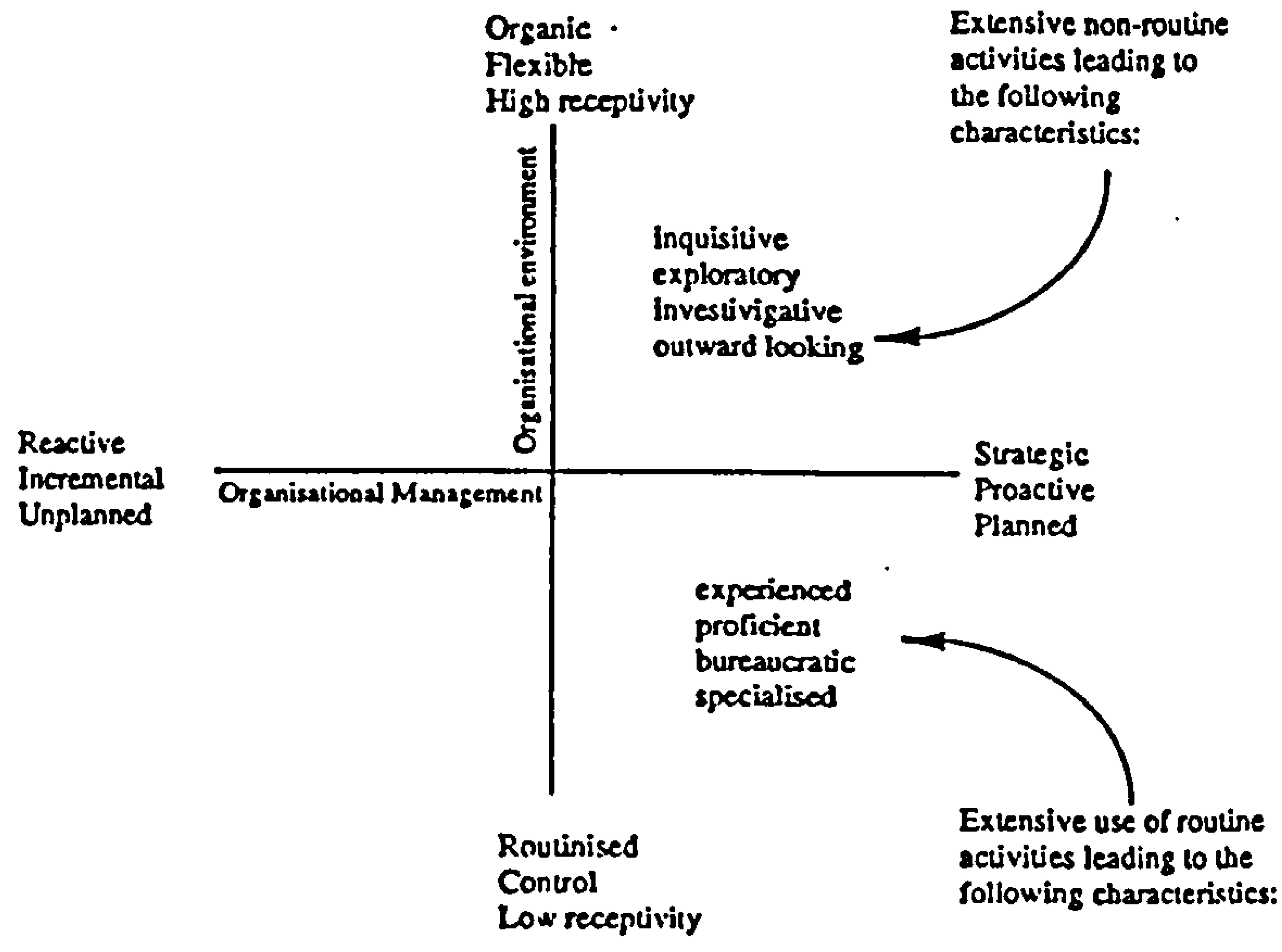

Fig. 6. Relationship between organizational management and organizational environment necessary for inward technology transfer. (Adapted from Cordey-Hayes [49].)

Notes

[1] These were the ICI watercare and solvents businesses (designated ICIw and ICIs respectively).

[2] A detailed analysis of these data can be found in Trott [12].

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The Use of Operational Research Tools: A Survey of Operational Research Practitioners in the UK

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Given the importance of understanding decision making processes within organizations, studies of the attitudes of Operational Research practitioners towards specific aspects of their work is a neglected area of research. This paper furnishes an account of a questionnaire-based survey of industrially based OR practitioners selected from the membership of the Operational Research Society. The objective of the study is to assess the views of OR practitioners regarding the modelling and problem solving tools that are available to them. In particular, the issues of technique selection, the treatment of uncertainty, and the perceived contribution of Operational Research to decision issues are investigated. Results from the survey contribute towards both a greater understanding of OR practitioners' perspectives on the decision support process and the development of a profile of the membership of the OR Society.

Key words: practice of OR, OR Society

INTRODUCTION

The roles played by the disciplines of Operational Research (OR) and Management Science (MS) in the decision support process and the effectiveness of OR/MS techniques are both well documented[1–6]. This is also a time at which OR/MS techniques are being applied to an ever increasing range of situations and problem areas (witness the development of Soft Systems Methodology[7] and the application of OR to Information Technology issues[8]). What are less well researched are the views of analysts regarding the methods and techniques that they utilize and their opinions concerning the contribution of OR/MS to the organization and its activities. The utility of such information is focused on two areas; contributing to the discussion surrounding the causes of effective OR implementation, and providing information that can be used in the development and dissemination of new theoretical and analytical tools for use by the profession[9].

Previous studies on the process of organizational decision making have tended to focus on decision-maker style[10,11] or the dynamics of group interaction during the decision making process[12–14]. The aim of this paper is to broaden the discussion surrounding decision support processes to include the attitudes and perspectives of the decision support specialist or analyst. Of particular interest is the role of the analyst as interpreter of, and interface between, the organization's own process/structures and its operating environment. Irrespective of the organization's activities, the analyst's influence on decision making may be very high in relation to his or her hierarchical position within the firm. The reason for this stems from the analyst's role as a rationalizer and interpreter of both the organization's structure and processes, and more importantly, of the relationships between the organization and the outside world.

The role of analysts as interpreters of the organization's 'reality' cannot be overstated. Rational/comprehensive approaches to decision making are based on the premise that the organization's activities and the behaviour of its environment can be understood and analysed. Formal assessments of the interplay between these two components are carried out by organizational actors who participate in the planning function. OR/MS practitioners often constitute the major part of this community. Hence, understanding the attitudes of analysts

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towards the methodologies and techniques they utilize can generate insights not only into the perceived utility of the tools themselves, but also into the analyst's adherence to the rational/comprehensive approach.

Previous studies of attitudinal influences on decision making processes have focused on the influence of cognition[15,16], and the effect of variances in problem structuring approaches[17]. The study reported below addresses a slightly different theme by emphasizing the relationship between the executor of formal analyses and the tools utilized during the analysis process. The results of a recent survey of a subset of OR practitioners in the UK are presented with the aim of identifying some broad trends in analysts' attitudes towards the tools they utilize. The survey was designed and executed with the support of the Operational Research Society (ORS) and used a subset of the ORS membership as a target survey population.

RESPONSE GROUP SELECTION AND DATA ANALYSIS METHODOLOGY

About 3000 membership records are held by the ORS, reflecting both national and regional membership patterns. The records are maintained on a computerized database with a number of sort fields available to aid the identification of subgroups. Sampling the entire membership of 3000 was considered inefficient due to cost and time considerations. Guidance for the selection of a subset of the membership for inclusion in the study came from the desire to access OR practitioners who both operate in a well-defined OR setting and have experience of the practical use of OR tools. Furthermore, as a result of viewing the OR practitioner (for the purposes of the study) as a problem analyst, it was important to reduce the incidence of respondents who might utilize OR tools as a secondary or subordinate feature of their employment activities. An appropriate selection field for meeting these requirements was constructed by focusing on the OR departments of larger industrial concerns, and the criterion for respondent selection was based on a cross-referencing of industry type and job title using the Society's database records. Consequently members whose main activities are in academia, commerce, the service industries and government/local authority institutions were excluded from the study. Table 1 provides a breakdown of the identified response group by industrial sector.

TABLE 1. *Sectoral distribution of ORS survey target population*

Industrial sector	No. of individuals
Electricity Supply	49
Gas Supply	86
Water Supply	10
Rail Network	9
Steel	32
Telecommunications	41
Chemicals	32
Coal	11
Oil Exploration & Supply	55
Shipping	7
Aircraft Manufacture & Transport	63
Total	395

Data collection was carried out by way of a mailed questionnaire sent to the target response group. Mailed questionnaires suffer from two important problems that the researcher is only partially able to influence; response rate and quality of response. Techniques for overcoming these difficulties have been widely covered in the literature[18,19], the general conclusion being quality of response. One such technique concerns the maintenance of respondent anonymity[20-22]. Of particular interest in this context is the work of Futrell and Swann[23] who found that anonymous respondents had a lower item omission rate to sensitive questions. A further consideration in this context concerns the corporate nature of some of the information required. Indeed some respondents abstained from completing the questionnaire on the grounds that the information requested constituted commercially sensitive details which, if accessed by the organization's rivals, would damage the firm's ability to maintain competitive advantage. This in itself is an interesting phenomenon as it suggests that the organizations concerned perceive their methods and techniques as a key resource of some value.

Resolving the trade-off between the desire to offer anonymity in order to enhance response quality and maintaining a record of which individuals from which industrial sectors had already returned a questionnaire involved two steps. First, respondents were assured in the letter that accompanied the questionnaire that the information provided would be treated in the strictest confidence and that the published results would not specifically identify any individual or organization. Secondly, each self-addressed reply envelope was marked with a unique reference number (partially derived from the ORS coding system) which reflected the industrial sector and personally attributed code number of each respondent. This approach proved generally successful and only one complaint was received concerning the use of the coding method.

An additional technique, which can be used to enhance both the quantity and quality of data is an undertaking to potential respondents to provide a copy of the survey results. Research on the provision of survey results to respondents has produced dichotomous findings with some studies exposing a positive correlation between the offer of such information and the level of response[24], whilst others have found no benefit over a range of response characteristics[25]. In this instance there were external reasons as well as internal ones for seeking to provide respondents with a summary of the results. Promoting a good working relationship with both the ORS and the respondents constituted a sufficient reason for suggesting that a summary of the survey's results and findings should be published in one of the OR Society's journals. This was acceptable to the Society and the intention to publish was relayed to the potential respondents in the covering letter. Consequently, many of the respondents expressed their interest in seeing the published findings of the survey. Piloting of the questionnaire took place at the Cranfield Institute of Technology amongst MBA students with an OR, Project Management or related background. The final version was distributed to 380 ORS members. After a 6 week period, this was followed up by 312 reminder letters, resulting in a total response rate of 30%.

Two types of analysis technique were utilized for assessment of the questionnaire returns. A small subset of the collated data lent itself to some form of statistical analysis. Simple frequency distributions and mean values were applied in these instances. The remaining data comprised free text responses to open-ended questions concerning the practitioner's attitude towards elements of his/her work. Analysis of this second data type was achieved by the use of a variant of Content Analysis[26].

Content Analysis has evolved into a general term for 'any research technique for making inferences by systematically and objectively identifying specified characteristics within text'[27]. Such techniques are typified by two characteristics. First, the data consists of verbal, written or other symbols that make up the content of the communication. Secondly, the analysis procedure aims to be objective and repeatable. Problems regarding the reliability of Content Analysis have been highlighted by, amongst others, Krippendorf[28]. However, a number of steps can be taken during the data analysis stage that improve the robustness of results. These include testing for the stability, accuracy and reproducibility of category and sub-group identification. Content analysis employs an explicit, structured activity sequence for assembling data, classifying or quantifying the data to measure the concepts under study, and examining the patterns/relationships. Interpretation can then be carried out within a precise and empirically robust framework.

In order to generate a basis for categorization of the responses, Berelson's comments on feasible units of analysis were considered and the unit of 'theme' were selected as being most appropriate[29]. Responses to each open-ended question were categorized, according to the theme of the response, by independent coders. These categories were then validated by asking an independent second party (with knowledge of the relevant terminology), to suggest a classification framework for the responses based on the focus of the question. A sorting process was then executed by randomly selected individuals to provide a distribution of the responses amongst the categories. As with the category formulation, the allocation procedure was repeated by several individuals, providing some level of reliability for the results. This type of approach, which utilizes multiple human coders to assess the reliability of categorization, has found support as a way to increase confidence in the results of Content Analysis when applied to questionnaire returns[30].

GENERAL CHARACTERISTICS OF THE RESPONDENTS

Questionnaires were eventually sent out to 380 of the 395 identified potential respondents. Overall, 30% of these targeted practitioners replied in some form (either by letter, by phone or by returning a completed form), and almost 23% of the total population provided a completed, useful response. This final figure is encouraging as a response rate for a postal questionnaire but somewhat low given the explicit support of the target population's own learned society. A major factor behind both the failure to respond at all and the failure to complete the questionnaire fully appears to be a surprising paucity of active practitioners. The vast majority of comments that accompanied non-completed forms mentioned the fact that the respondents were no longer directly involved in Operational Research activities. If this ratio is extrapolated, over 20% of the Society's membership may currently not be OR practitioners. Earlier studies of ORS membership also suggested low levels of congruence between membership of the society and activity as a full-time OR practitioner[31,32]. Such findings are, however, in keeping with earlier studies that suggested that many OR professionals are highly mobile with regard to higher management positions[33]. Several aspects of the data compiled from the survey returns can be compared with previous studies of the OR communities in the UK and the USA.

For example, respondents from the survey reported here had an average of 11.3 years experience in an OR position. This contrasts with a figure of 13.7 years in Doukidis and Paul's survey[34] and 11 years in Carter's 1987 study[32]. In order to assess the relative use of specific OR tools, a listing of techniques was extracted from the recommended keyword list used by the *Journal of the Operational Research Society*, and respondents were requested to indicate of which techniques they had practical experience (Figure 1).

Detailed comparison of these trends with previous studies of OR technique use is problematic. Both the characteristics of the response group (limited to a subset of the membership) and the contextual bias of the question itself make a statistical analysis of longitudinal trends difficult. For example, two recent ORS surveys[32,34] used a scale of 1–5 to assess the frequency of use of certain techniques. However, the survey reported here asked for information about respondent's practical experience of specific techniques (i.e. whether the respondent had ever used the technique in a workplace setting), with no indication of frequency of use. Two other relevant surveys by Eilon *et al.*[33] and Conway[35] generated more comparable responses by prompting for a complete listing of the use of techniques over a specified time period. Several broad trends can be identified from these data sets. First, both experience and utilization of statistical methods have declined sharply over the past 25 years. Conversely, simulation and forecasting continue to be widely used. A third group of techniques, which includes linear programming, scheduling and queueing theory, can be characterized as being widely understood, but poorly utilized. Additionally, Figure 1 suggests that several relatively new OR techniques, such as fuzzy set theory and quadratic programming, have yet to find widespread application. Finally, when compared with previous data, the responses shown in Figure 1 show a relatively high level of experience in project management techniques and decision support systems. Such a trend could be symptomatic of the use of OR methods in an increasingly diverse set of management activities.

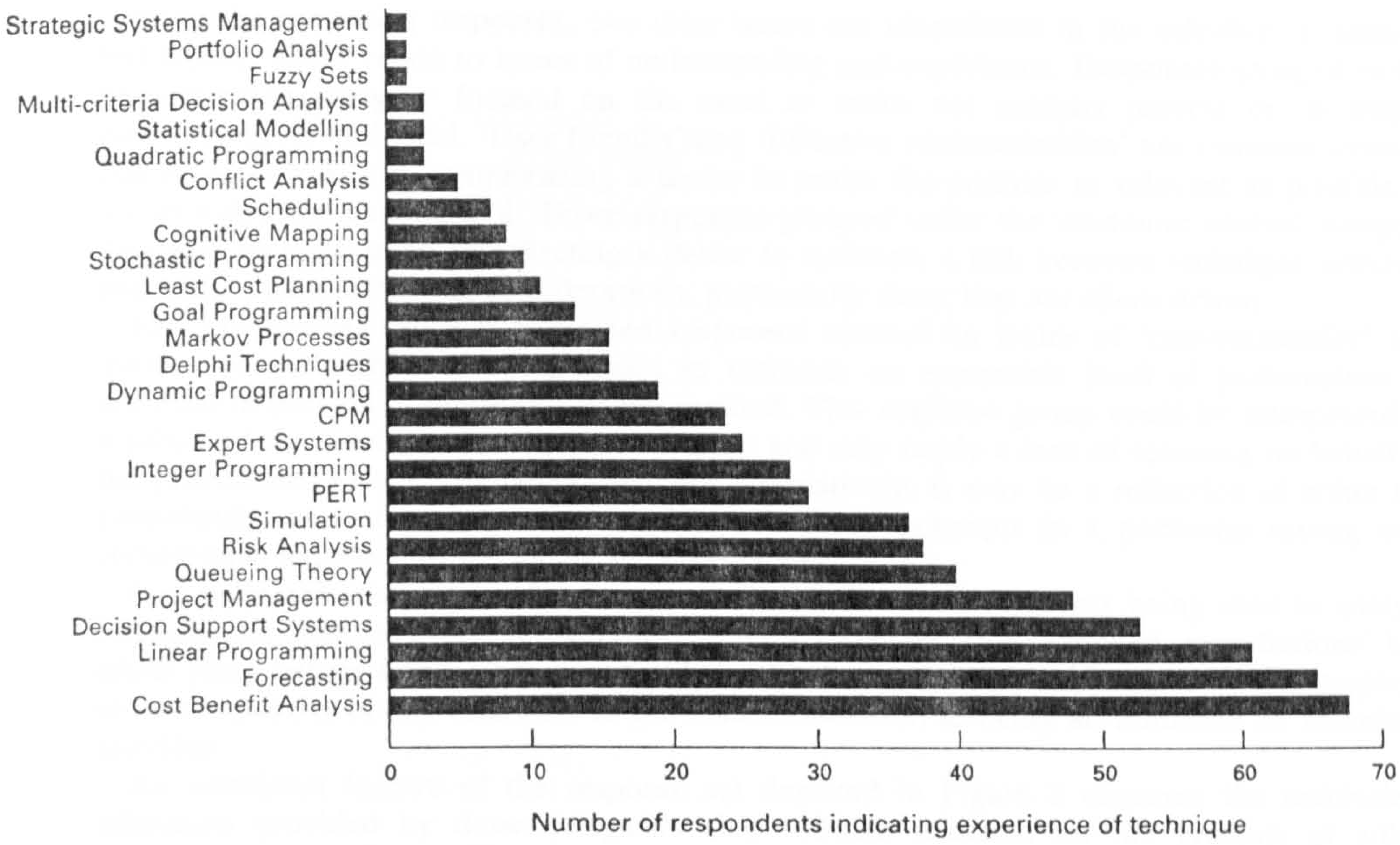

FIG. 1. *Use of techniques by OR practitioners.*

RESULTS FROM THE SURVEY

Respondents were asked to consider a recent project that involved the use of a specific OR technique. They were then requested to focus their responses to the remaining questions on this activity. Hence, continuity of subject was achieved across responses for each questionnaire return. Figure 2 shows six categories of response derived from answers to a question asking why the selected technique was chosen rather than possible alternatives.

The responses categorized as 'most appropriate' cover a range of comments that were interpreted by those involved in the Content Analysis procedure as reflecting a neutral attitude by respondents towards the adoption of a selected technique. Despite this, it would be unwise to infer that these respondents had no particular reason for technique selection. The definition of a technique as 'appropriate' may be derived from any one of the other factors indicated in Figure 2 (e.g. a proven record or the simplicity of the approach). Consequently, in the context of the other responses, this grouping is best classified as indefinite rather than neutral.

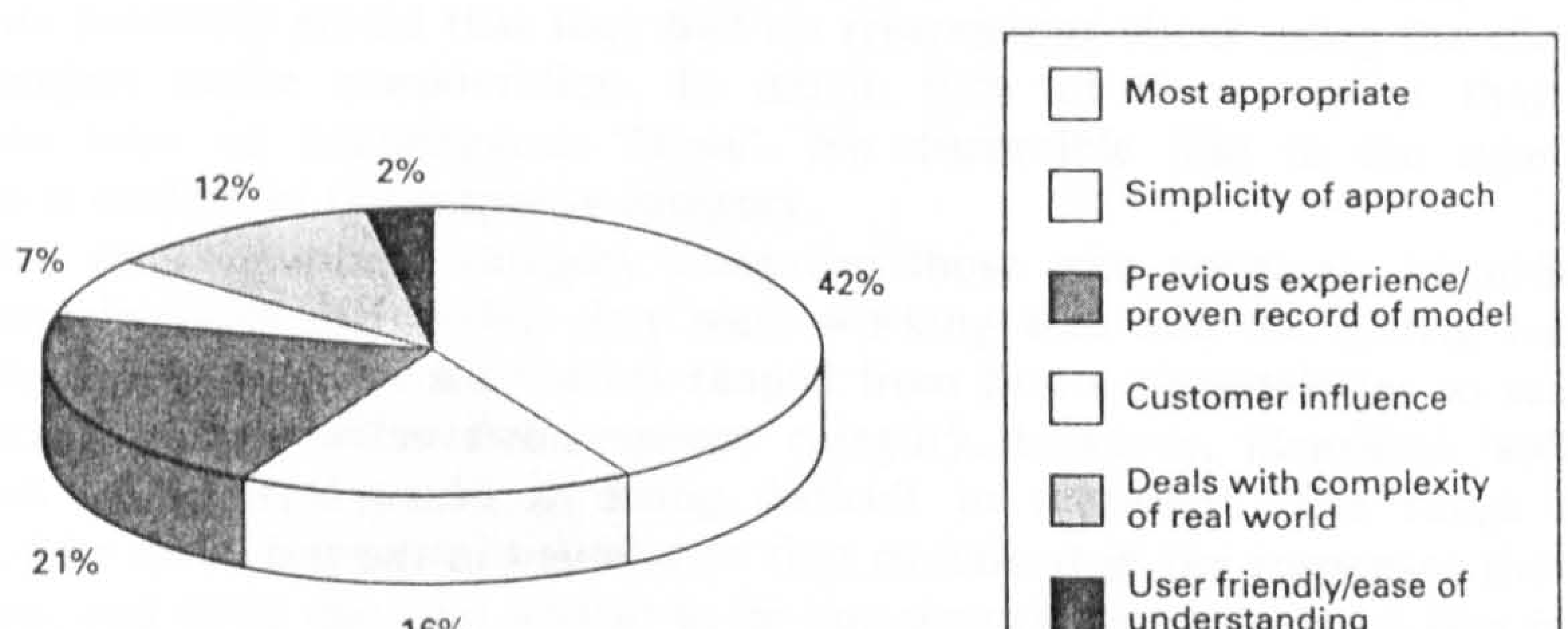

FIG. 2. *Justification for using selected OR technique.*

From the remaining responses, two clear issues are identifiable in the selection of analysis techniques. These relate to issues of understanding and experience. Responses grouped in the understanding category focused on the need to make the analysis process or its output comprehensible and lucid. 'User friendly' and 'Effective communication' are common terms in this response category, emphasizing a desire to make the analysis as relevant as possible to use as a decision making tool. Those responses grouped under the 'customer control' category may also be considered as reflecting a desire to maintain a link between technique selection and wider decision making considerations, particularly those that are client driven.

The experiential category contained responses centred on issues of 'conventionality' and 'proven record'. This reflects a desire to maintain an acceptable level of performance as achieved in previous applications of the method. This response group could be interpreted as a subset of the 'best one for the job' category and may imply a lack of scanning on behalf of the practitioner for an alternative method. Alternatively, it may be a reflection of either the consistently successful implementation of a particular technique in a particular setting or a conservative approach to the use of such techniques.

It is noticeable that none of the respondents alluded to any process being used to analyse formally the options available, although several intimated that 'detailed consultations' had taken place before a technique was finally adopted. A further characteristic of this response set is the paucity of any reference to problem formulation as being an influence on technique selection.

An additional feature of the response set depicted in Figure 2 concerns the ambivalent inferences provided by those categories that indicate selection on the grounds of either simplicity or complexity. There was no obvious distinction between the types of technique being commented on in these two response categories. In particular, simulation techniques are mentioned more than once in both categories. Hence, technique selection does not appear to be related to the relative simplicity or complexity of any particular method. More significantly, responses in the 'simplicity of approach' category included the following typical comments against the use of more sophisticated and involved techniques.

- Use of more complex methods does not result in a substantial increase in accuracy.
- Problems associated with describing complex models to senior management.
- Data not of sufficient quality.
- Time and resource constraints.
- Scope of the project limited.

Conversely, none of the responses categorized under the heading relating to a desire to capture complexity made any effort to justify the decision *not* to use a simpler technique. Finally, if both the 'simple' and 'complex' categories are unified, over 25% of respondents commented on some sort of trade-off between different levels of complexity as constituting one element of technique selection.

Figure 3 depicts responses to a question that prompted respondents to identify any reservations they might have concerning the use of the selected technique. Over 30% of respondents positively stated that they had no reservations about using the chosen technique for the project under consideration. In detail, 92% of those replies that indicated no reservations were an unambiguous 'None'. No discernible bias in the type of technique referred to is evident in this response category.

The other major response category comprises those who positively identified sources of incongruence between the models they were working with and the system being modelled. The origins of incongruence themselves ranged from future uncertainties to scale effects. By far the largest subset within this response category, however, identified 'soft' or 'human' components of the real world as being difficult to represent. The range of techniques represented by these responses is similar to that contained in the responses that identified no reservations, and there does not appear to be any sectoral or experiential bias in either set. A further significant response category was that containing responses centred on the ease with which the technique could be communicated to either the user or other developers.

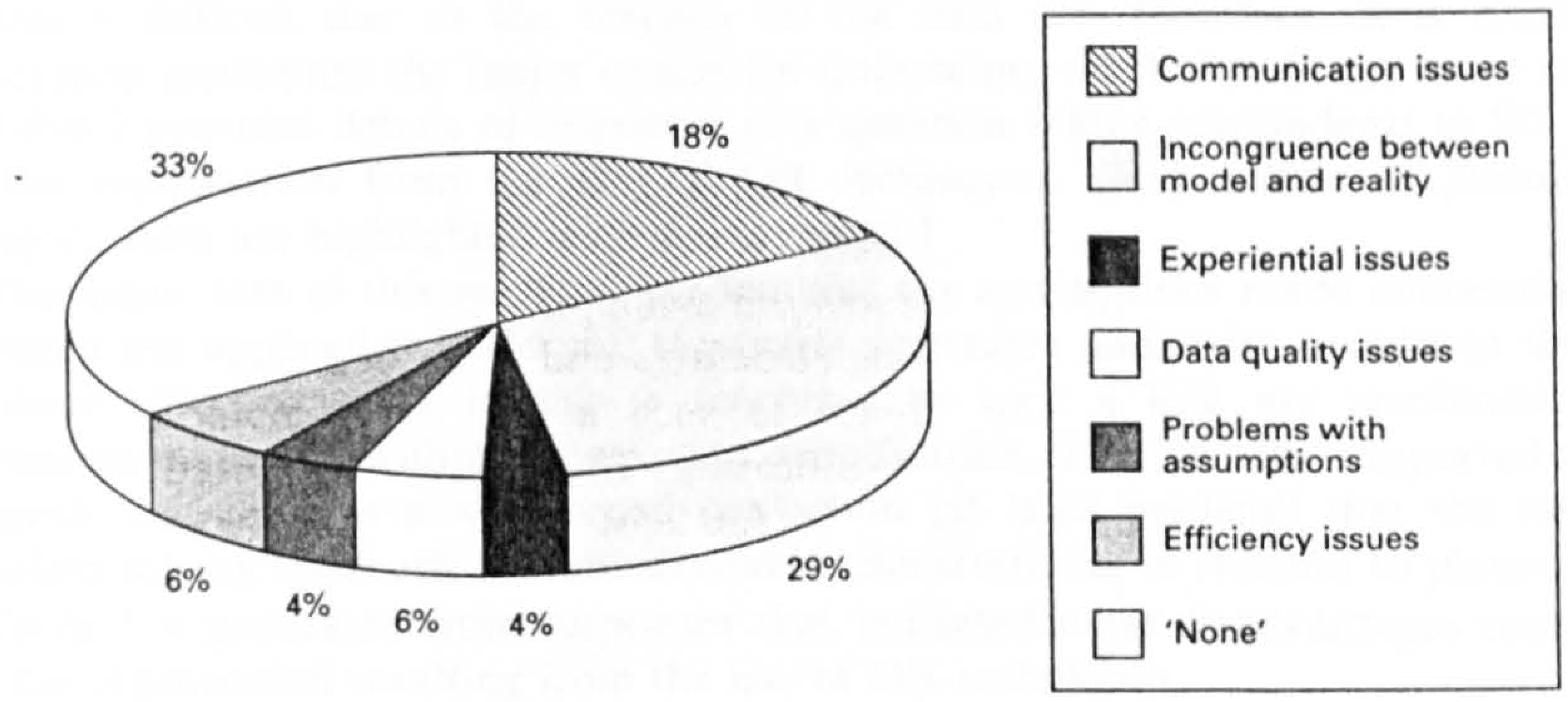

FIG. 3. *Reservations held regarding the use of the selected technique. (Percentage of total responses in each category.)*

In reply to a question asking what sources of uncertainty were associated with the project, doubts relating to either the accuracy of current data or the possibility of future data/boundary conditions changing constituted 72% of all responses. Comments within this category concerning the means for addressing such sources of uncertainty are depicted in Figures 4 and 5. (NB: respondents were able to list more than one source of uncertainty and more than one method for combating them.)

Doubts regarding the accuracy of data used in the model were mainly addressed by variants of Delphi-type techniques, involving a process of consultation with either an expert or the customer in order to provide a consensus on data values. Sensitivity analysis, estimation and weighting techniques were also used but not to the same extent as the consultative procedures. Methods for dealing with uncertainty regarding the future state of model variables or boundary conditions focus strongly on the use of scenarios with alternative methods, including the use of expert opinion and assuming accuracy. Interpretation of these

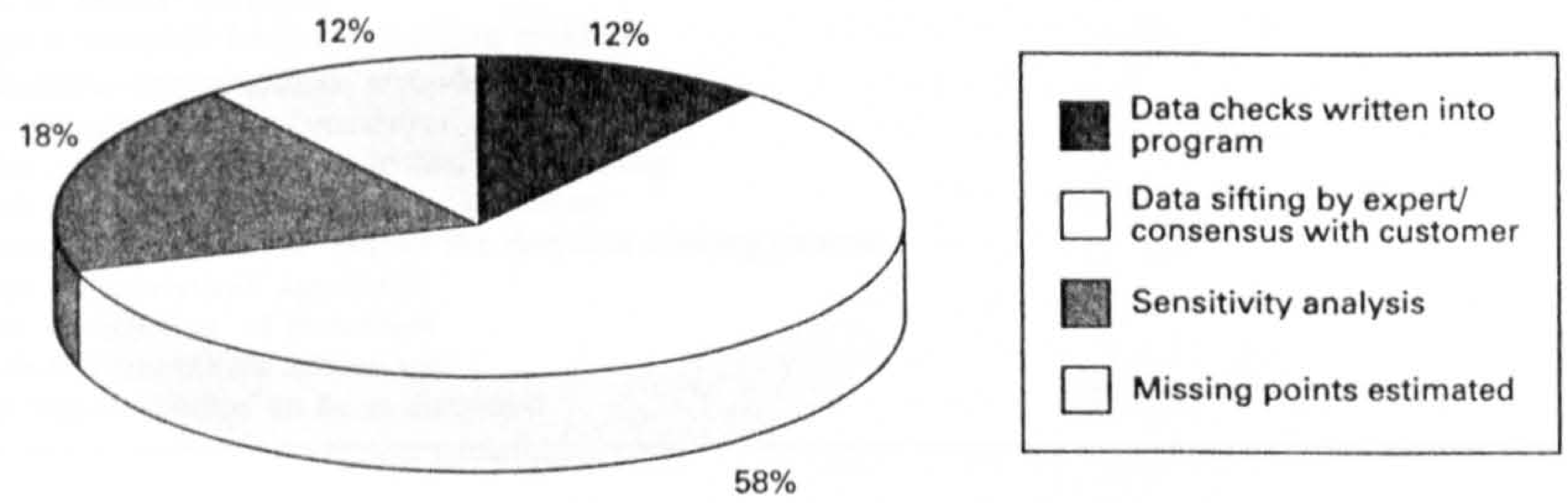

FIG. 4. *Techniques for dealing with sources of doubt. (Subset relating to accuracy of data being major source of uncertainty.)*

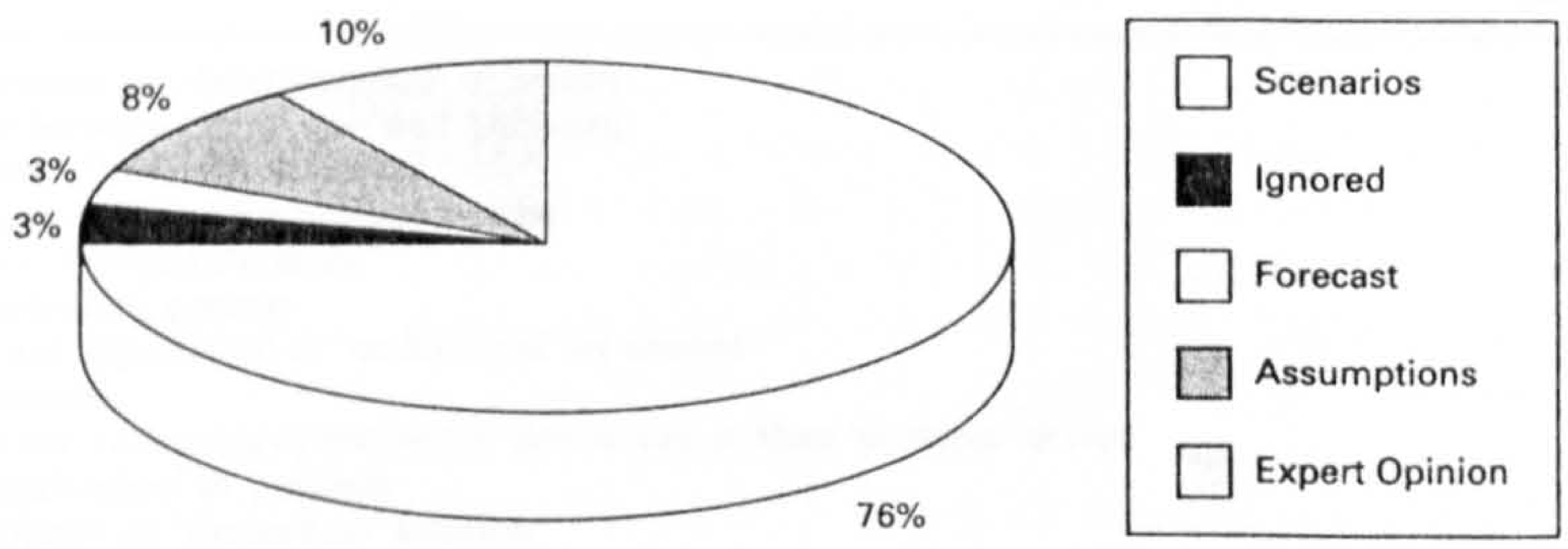

FIG. 5. *Techniques for dealing with sources of doubt. (Subset relating to changes in model parameters as being the major source of uncertainty.)*

results is difficult due to the fragility of the data set. However, it is clear that scenario generation constitutes the major option for uncertainty resolution in the cases surveyed.

Table 2 provides details of responses to a question asking respondents to list the advantages to the organization from the use of OR techniques. (Key words or phrases used during categorization are highlighted with quote marks.)

The major bias of this response set features the assumptions made concerning a correlation between the application of formal reasoning structures and some benefit to the organization. If those categories that include a reference to such a link are combined, over 50% of comments made fall within the relevant classification. This broadly supported response group suggests that there is a widespread conviction (at least publicly) that the rational/objective problem solving approach exhibits desirable characteristics in relation to planning.

Table 3 is generated from responses that indicated what disadvantages could be identified for the organization resulting from the use of OR techniques.

The major cause of concern for respondents in the context of OR technique disadvantages is focused on the process of result interpretation and application. There is obviously a very strong feeling that output from OR tools is prone to misuse.

On the final page of the practitioner questionnaire a space was provided in which respondents were invited to comment generally on their experience of the use of OR techniques. The following discussion is based on a textual analysis of these comments.

The overwhelming impression given by these comments concerns the emphasis given to OR as an approach rather than as a set of techniques. More specifically, the human-centred

TABLE 2. *Identified advantages to the organization from the use of Operational Research techniques*

Identified advantage	% of comments focused on this issue
Provides a broader 'understanding' of often 'complex' problems	13
Develops a 'scientific' approach based on 'quantification'	11
Allows a 'structured' approach to problem analysis	10
Constitutes an 'independent'/'objective' analysis	10
Resultant decisions made/seen to be made on a 'rational' basis	9
Ensures 'cost effective' decisions/'effective' resource allocation	9
Results in 'better' decisions	6
Provides a 'rational' basis for decision making	5
Miscellaneous organizational considerations	5
Allows 'scenarios' to be considered	4
Provides a 'logical' approach to decision making	4
Expands the 'range' of 'alternative solutions'	4
Improves 'communication' within the decision making process	3
Provides an 'analytical' approach	3
Enables 'monitoring' of processes	2
Engenders 'competitive advantage'	1
Allows 'accountability' to be maintained	1

TABLE 3. *Identified disadvantages to the organization from the use of the Operational Research techniques*

Identified disadvantage	% of comments focused on this issue
'Misuse'/erroneous 'interpretation' of results	34
Mismatch between 'technique' and 'problem'	10
Ignores 'soft'/'behavioural' issues	9
Used as a 'substitute' for 'common sense'	8
Engenders 'Analysis Paralysis'	8
'Time' consuming process	7
Problem not appreciated or 'understood' by analyst	6
'Costly' process	6
Solutions are 'technology'/'technique' driven rather than 'problem' driven	4
'Oversimplification' of problem	4
Over-emphasis on 'theoretical' solution	3
Over-emphasis on 'rationality'	2
'Not suited' to present day business problems	1

characteristics or 'way of thinking' engendered by an OR background are emphasized as being of greater benefit to the organization than knowledge of formal analysis techniques. Indeed some respondents expressed reservations about tackling a questionnaire which expressly adopted a technique-based typology of the profession.

In a similar vein to this lack of formality were several comments to the effect that predefined techniques are rarely, if ever, utilized without some measure of modification and adaptation to provide a contextual setting (support for this phenomena can also be found in Conway's 1984 study[35]). Other issues raised included the following.

- The important role played by inter-personal skills in OR activities.
- The need to ensure a comprehensive understanding of the problem.
- A positive, if somewhat qualified attitude to the emerging 'soft' techniques.
- The problem of winning over senior managers before new techniques can be adopted.
- The important role played by 'common sense'.

The final issue is representative of a somewhat perplexing conundrum that emerges from the study as a whole. Despite the exhibited emphasis on the importance of 'rational' and 'structured' approaches and 'analytical'/'scientific' processes, there is widespread reference to 'common sense'. It is unclear just what kind of skill or knowledge is being referred to with this term but the context in which it is typically used suggests that it is a desirable characteristic of decision makers. Overall, some 34% of respondents alluded at some point in the questionnaire to common sense as being under threat from over-complicated analyses.

DISCUSSION AND CONCLUSIONS

The survey design objectives, the limited nature of the response group, and the data analysis methodology preclude the adoption of any hard and fast conclusions regarding the attitude of analysts to the tools they utilize. Similarly, there has been no attempt to prove any causality between different aspects of the decision support process. Therefore, what follows is a general discussion of the survey's findings, drawing together topics and trends to formulate an overview of the subject area. In this way it is hoped both to identify pertinent elements of interest and provide indications for further work.

Three broad themes can be identified in the questionnaire responses that warrant comment. The first of these concerns the emphasis placed by respondents on 'rationality' or a 'rational approach'. The findings support the view that rationality is a key positive feature of analysts' perceptions of formal assessment techniques. Whether the source of this emphasis lies within the organizational or OR group culture (or both) is unclear from the research findings. From the organizational perspective, evidence for the influence of a dominant organizational paradigm based on rationality has been identified by both DiMaggio and Powell[36] and Zucker[37]. Other institutional theorists make the point that organizations promote the aura of rationality as a legitimate framework for decision making as external sources of support would treat anything else with suspicion. In contrast, the role of formal analysis techniques in promoting a culture of rationality has been identified by both Edelman[38] and Feldman and March[39] who uncovered evidence for the symbolic use of language and information to convey rationality and thereby legitimize organizational actions. Furthermore, Quinn[40] suggested that formal analysis procedures may help to raise 'comfort' levels, and others have illustrated their role as *post hoc* rationalizers of decisions[3,41]. What is interesting to note with regard to this and other studies on the use of OR tools, however, is the range and diversity of techniques available to, and used by, practitioners. This reflects the findings of Langley's comprehensive study, which focused on why formal analysis techniques are used. Emphasizing the role played by formal analysis in communication, direction and control, Langley commented that 'Organizations that undertake a great deal of formal analysis may not necessarily be more rational—but they are likely to be more pluralistic'[42].

The second theme to emerge from the study relates to the reservations held by practitioners concerning the use of a selected technique. It is clear from the survey results that respondents are acutely aware of the limitations of the tools they use and are concerned to communicate these limitations to decision makers and clients. Specifically, they are keen to ensure that details concerning assumptions, data sources, boundary conditions, and limits to application are communicated. In many instances, there was an emphasis on the need to detail the *failings* of developed models so as to draw attention to their relevant scope of application. In the context of the decision making progress, the Management Studies literature identifies a phenomenon whereby individuals act to support their own interests during a decision analysis process[43]. By both emphasizing a common and rational approach to problem analysis and engaging in the type of information promotion described above, OR practitioners can be seen to provide a counterbalance to the divisive effects of self-serving interest groups.

The third theme that can be identified in the survey findings appears to be in conflict with the second theme discussed above. A significant level of confidence in the revelance of the techniques adopted to the problem at hand is evident from the survey responses. How can evidence for both confidence in technique selection and an awareness of the failings of techniques be reconciled within the same response group? A possible source for this incongruence would be the type of technique being commented on by individual respondents. However, the data exhibit no significant correlation between comments concerning confidence/awareness of failings and type of technique being referred to. A second explanation for the apparent dichotomy is rooted in the professional training of the OR practitioner, which both lays significant emphasis on the limitations of technique application *and* encourages the development of confidence in the correct use of the techniques being presented. Hence, OR practitioners are confronted with the task of maintaining a balance between the limitations and benefits of the tools they utilize; a dialectic process that needs resolving at a number of levels.

A greater understanding of how OR practitioners balance the competing claims of technique limitation and professional confidence is essential for the development of more effective OR techniques and formal decision-making processes. A useful behavioural model that may provide a template for understanding this issue is that of 'role conflict'. Interpreting the above outlined data within a role conflict context suggests the following explanation. As company employees, OR practitioners are confronted with a system that supports their livelihood, providing a framework for both career and financial advancement. Under these conditions, a particular set of behavioural attributes are dominant, characterized by company loyalty, expressed self-confidence, and positivism. Conversely, as members of a professional society (and one with very close links with academia), an alternative set of behavioural attributes is evident, this time represented by enquiry, scepticism, objectivism and a readiness to admit ignorance. Much research on 'role conflict' in the fields of organizational theory and psychology is based on the role episode model[44]. However, conflicting empirical results have restricted the development of a robust theory and recent articles have called for a re-evaluation of the field[45]. Several groups of organizational actors (e.g. boundary spanners) have been identified as being particularly susceptible to both intra-role and inter-role conflict[46]. More pertinently to this study, professionals who operate within complex organizations have been shown to suffer conflicts of interest between a bureaucratic organizational setting and a professional approach to their occupation[47,48].

Surveys on role conflict have been carried out on many professional groups. However, there are no published references indicating a specific study of OR practitioners. Given the important role played by analysts as formalizers of the organization's interface with its operating environment, it should be a matter of concern to decision makers how decision support staff view the utility of their tools. Further work in this area could enable a profile of both analysts' and decision makers' attitudes towards, and levels of belief in, specific techniques and methods to be constructed. Such research should begin by determining to what level OR practitioners themselves recognize a conflict of interest between technique limitation and professional confidence. Subsequently, work is needed to identify the roles of education and the experience of technique use in influencing not only tool selection but also the modification and adaptation of specific techniques to fit organizational problem contexts.

This research has both provided general information concerning a subset of the membership of the ORS and investigated the attitudes of this group of practitioners towards the use of the techniques and methods they employ. Results from the survey suggest that in an industrial setting, OR practitioners are both aware of the limitations of the tools they utilize and are concerned to communicate such deficiencies to makers and clients. There is also evidence to show that these practitioners perceive the main benefit of Operational Research as being the promotion of a rational approach to decision making. However, other data point to a possible dichotomy between awareness of technique limitations and confidence in the selection and use of techniques. A tentative explanation for such a dichotomy, based on the role conflict model, has been presented and further work called for in order to build up a more detailed picture of OR practitioners' attitudes to their tools.

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AGRICULTURE, POLICY AND ENVIRONMENTAL DEGRADATION: THE CASE OF THE ARGOLID VALLEY

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Abstract

Farming across much of the Southern Mediterranean has evolved in response to the uncertainty of its natural and climatic conditions with small units, part-time farmers and diverse cropping. It is argued in this article that much of European agricultural policy has been based upon criteria of efficiency which have resulted in standardisation and higher unit production. Using the Argolid Valley in Greece as an example it will be seen that the adoption of policies directed at the farmer, the crop and water resources can encourage, and entrench, intensive monocropping practices while exerting considerable strain upon the natural resources of the area. It is maintained that the degradation of natural resources, and the decreased potential for income generation resulting from this, have resulted in a reduced set of options for farmers and the inequitable distribution of those options among them.

Résumé

Dans les pays sud-méditerranéens, l'agriculture a evolué face aux aléas de ses conditions climatiques et naturelles en donnant lieu à de petites exploitations, des agriculteurs à temps partiel et à des systèmes de culture diversifiés. Dans cet article on soutient qu'une grande partie de la politique agricole européenne s'est basée sur les critères d'efficience qui ont abouti à la standardisation et à une production unitaire plus élevée. Prenant la Vallée d'Argolide comme exemple, on constatera que l'adoption de politiques orientées aux agriculteurs, aux ressources en eau et aux cultures, peuvent encourager et consolider les pratiques de la monoculture intensive tout en exerçant une pression énorme sur les ressources naturelles de la région. On soutient que la dégradation des ressources naturelles et la moindre potentialité pour la création de revenu qui en résulte, ont réduit le nombre d'options disponibles pour les agriculteurs et donné lieu à une répartition inéquitable des ces options.

Agricultural policy has been increasingly directed towards the improved efficiency of farming activities[1]. The effect of this in some areas has been to encourage a move towards increased production and standardisation with insufficient consideration of the impact upon the physical environment (Clunies-Ross and Hildyard, 1992; Manitea-Tsapatsaris, 1986). This has had disastrous effects in areas of the southern Mediterranean where, over time, farming structures have previously emerged in response to local physical conditions.

Paradoxically the failure of some parts of the region to adopt «more efficient» agricultural production systems has been attributed to the continuation of the very characteristics that have historically enabled it to survive without threatening local natural systems. The nature of this change has not just highlighted a perceived «backwardness» in the southern Mediterranean, it has also led in certain instances to an inequitable distribution of the costs and benefits within its regions, particularly in terms of the ability to respond to declining natural resources.

The physical environment of the Mediterranean is inherently more vulnerable than that of the more temperate regions of Northern Europe. There is considerable variation in the temperature and precipitation levels from year to year and more importantly a disjuncture between the two. This, alongside the geomorphologic and geological variation of the region, has created an environment that will support a wide range of vegetation. However, with the exception of indigenous crops such as olives this is not matched by an ability to produce yields at the levels achieved in Northern Europe (Ruiz, 1988).

Agriculture in the region has, therefore, been determined by the physical and social landscape in which it operates. Traditionally this has involved high levels of direct consumption and diversity in the crops grown. Agricultural holdings are generally small and divided into a number of parcels[2] with a high percentage of the local work force actively employed in farming, often in a part-time capacity[3]. These characteristics (i.e. multiple job holding, small farms, local markets and diverse low input cropping) have supported an adaptive agriculture capable of responding to the uncertainties of the physical and climatic environment. They are, however, invariably less efficient in terms of the economic criteria that have been central to recent agricultural policy. Indeed where some of these «structural deficiencies» have been overcome (i.e. through the establishment of co-operative organisations) the resulting loss of crop diversity has often been accompanied by the degradation of natural resources.

In Greece the failure to meet criteria of economic efficiency has frequently been accredited to the «structural weaknesses» of Greek agriculture[4] rather than the relevance and suitability of the policies introduced for different localities (Green and Lemon, 1995). The failure of policy to account for physical and social difference can force the farming community into a treadmill of intensive practice that ultimately jeopardises the natural resource upon which it depends, and the social context in which it operates.

This paper will draw upon research carried out in the Argolid Valley in the Peloponnese of Southern Greece. It will provide one example of an agricultural system that has developed along an unsustainable path. This has coincided with the distribution of environmental costs among the farming community being perceived as inequitable by many within that community. The field work for the study was carried out in two phases. Firstly a series of thirty extended semi-structured interviews were undertaken with farmers, agronomists, hydrologists and other key actors in the area. These were intended to establish the range of agricultural agendas (Lemon and Park, 1993) that required further investigation and formed the basis for the second part of the study. This phase elicited more detailed information about farming activity and water use and consisted of two hundred structured interviews (Lemon, Seaton and Park, 1994).

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[1] For example see Council Regulations (EEC) Nos. 797/85 and 2328/91 «*On improving the efficiency of agricultural structures*».
[2] In the Argolid study the average farm size was five hectares divided into five parcels of land
[3] Percentage of population employed in agriculture: Greece 24.5%, Portugal 17.8% compared with UK. 2.1%, Netherlands 4.6%.
[4] i.e. Small fragmented land holdings, inefficient marketing organisations and insufficient rural infrastructure (Spanopoulu, 1990; Polopolus, 1989; Demoussis and Sarris, 1988)

Both sets of interviews were undertaken by local agronomists who were accepted by the farming community.
The area has considerable variation both in its natural features (soil, hydrology, topography etc.) and in the type of farmers working the land (full/part time, mixed farming/monocropping etc.). In order to represent this variation considerable time was spent attempting to define a useful zoned structure. The need to adopt contiguous zones for modelling purposes (Allen et al., 1994), and the different spatial structure of the various attributes (i.e. topography, water, soil, crop, frost), made it particularly difficult to identify zones which represented combinations of those attributes while retaining their individual integrity. The provisional zones, represented in Figure 1, were established through a series of extended discussions with local agronomists(5). Subsequent analysis of cropping and water use data broadly supported this structure.
The paper will be divided into three parts. The first section will describe the changes in agricultural production for the Argolid Valley, the technology employed to support it and the qualitative and quantitative condition of the natural resources. The changes will then be related to a range of policy instruments that have been introduced by different levels of government (local, national, European) and have focused upon the farmer, the crops and the water supply. The final part of the paper will suggest a number of more sustainable policy scenarios for the Argolid.

Table 1 ***Change in main crops (hectares).***

	Arable			Trees	
	Cereal	Vegetable	Citrus	Orange	Olive*
1960	18933	5809	6862	5041	1783
1964	16464	5002	8119	6487	2449
1972	10961	3846	10452	8356	2600
1980	9469	3173	9482	7469	2885
1986	7174	2887	10784	8733	2852

Source: Greek Service of Agriculture.

* per 1,000 trees.

Background to agricultural change in the Argolid

The Argolid Valley is situated in the Argolis region of the North-eastern Peloponnese in Southern Greece (**figure 1**). The total catchment (approx. 1100sq. km.) is divided into 38,600 ha. mountains, 26,500 ha. hills and 42,000 ha. valley. The valley itself is divided into 29,500 ha. cultivated land, 7,800 ha. pasture, 3,000 ha. urban surface and 1,750 uncultivated land. The soils of the valley are deep (silt, loam and clay) and fertile whereas those of the hillside are stony and of poor irrigability.
The area is dominated by agriculture with fifty percent of the working population involved in farm work of some form although many of these have other sources of income(6). Agriculture is also the main consumer of water in the area using approximately 140 million cubic metres of water (89% of the total) compared with ten million m^3 for potable water and less still for other industrial uses (Argolid Association of Agronomists, 1992).
The climate is predominantly Mediterranean with temperatures ranging from the extremes of minus five centigrade in January to plus forty in the summer months. The temperature away from the sea is approximately two degrees lower. Mean rainfall for the area is over 500 mm and is usually recorded within ninety days (throughout the year). These factors lead to a high relative humidity in the winter (when there is most precipitation) with the result that frost poses a major threat to crops. This is most evident in the central areas where there is the greatest proportion of irrigated agriculture, in particular citrus crops(7).

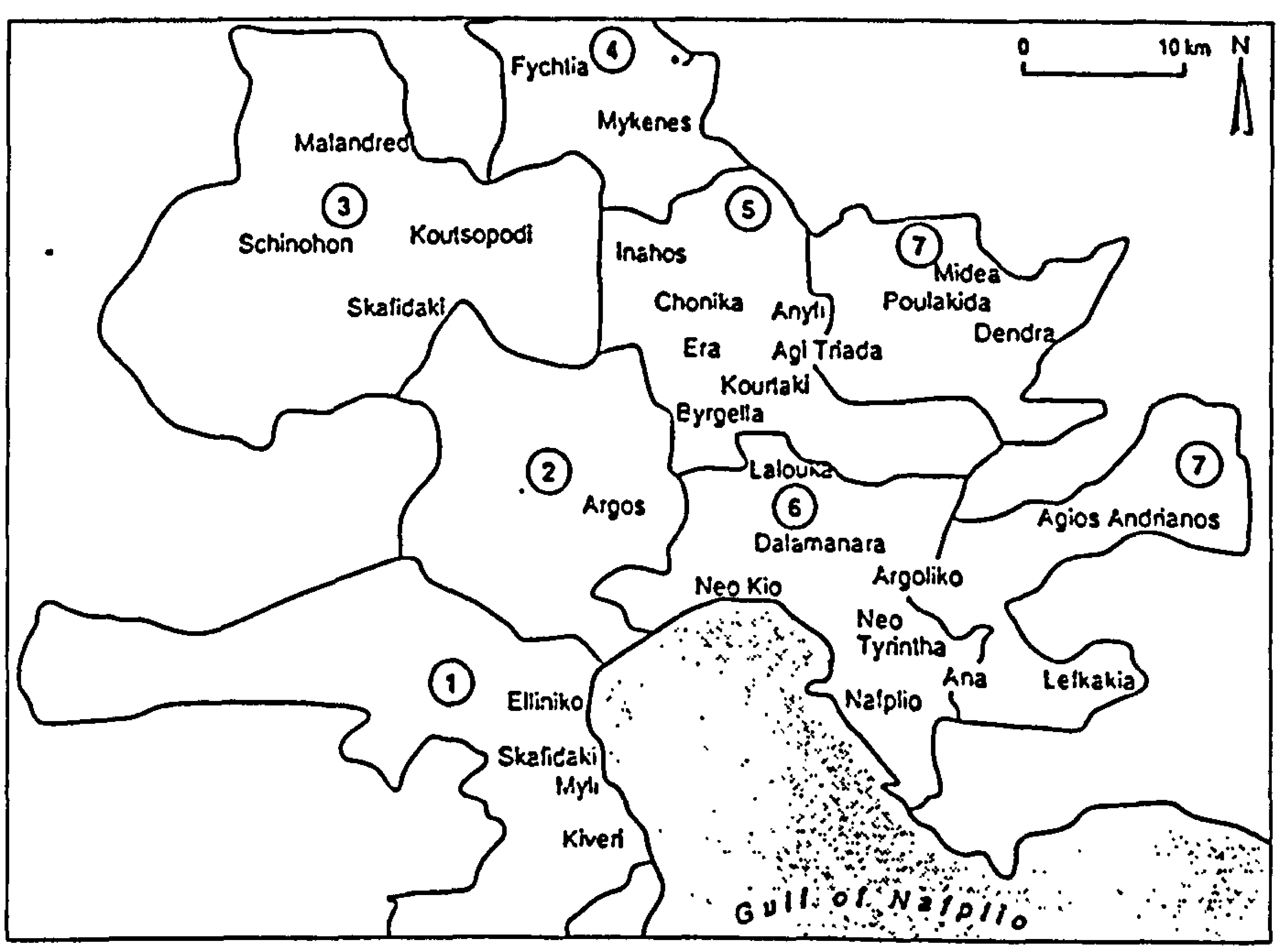

Figure 1 - The Argolid Valley with study zones.

Production, technology and degradation

The use of irrigation water has increased markedly over the last fifty years. Before 1940 there were 4,000 hectares of irrigated land compared with over 20,000 hectares today. The majority of irrigation water is obtained from ground water through wells and bore holes (95-125,000 million cubic metres per annum, dependent upon precipitation levels). An additional twenty five million cubic metres is acquired from springs via specially constructed pumping plants and distributed through the plain by aqueducts.
Table 1 shows the general movement away from subsistance, and predomi-

(5) The interviews lasted approximately eight hours.
(6) Part time farmers in the central zones are often professional people who commit less time to working the land and consider farming to be their second occupation. By comparison those who farm part-time in the peripheral zones often do so because they cannot earn a sufficient income from poorer quality land.
(7) The problem of frost is perceived by many local farmers to have become far worse with the increase in irrigated trees.

nantly rain fed, crops (cereals, vines, olives and grazing), with a limited amount of irrigated production (vegetables), towards a more intensive and less diverse agriculture based upon fruit production.

This transformation towards irrigated monocropping is most pronounced in the central and coastal areas, a more diverse production system is apparent as one moves towards the outer zones (**figure 2**).

Table 2 shows the distribution of irrigated land throughout the study area. It is noticeable that the percentage declines away from the central plain towards the foothills in zones three, four and seven. The introduction of orange trees provides a temporal indicator of the movement of irrigated agriculture from the centre outwards.

It can be seen that the size of farms also increases away from the centre alongside a decrease in the productivity (for oranges) per hectare. Poorer soils, slope, water depletion etc. have all restricted the productive capacity in zones three, four and seven-as has the limited access to alternative water sources. Farm size is not therefore an appropriate indicator of potential income generation. Paradoxically the mean price per kilo of oranges is noticeably lower for zones five and six which are the main citrus producers and the least diverse farmers. To understand this it is necessary to consider the relationship between crop and market characteristics and the farming structures in place to produce and sell.

With the exception of the picking period([8]), oranges are not labour intensive to produce([9]). This has meant that the monocropping of citrus has emerged alongside a pluriactive farming community (Arkleton Trust, 1988). In the central areas this form of farming often provides a supplementary income to other occupations whereas in the periphery multiple job holding has often been forced upon farmers because of difficulties in generating sufficient income from the land (Damianos et al., 1991). Two important points arise out of this which help to explain the price differential mentioned above.

- The dependence upon citrus production in the central plain is reinforced by the high proportion of part-time farmers who are unable to farm in a manner which is more time consuming than that required for the production of citrus fruits([10]).
- They are less likely to have the time, or the inclination, to sell their produce at local markets, albeit it for higher prices than can be achieved through the co-operatives and the supported price system. The adoption of local markets for citrus, in conjunction with other crops, is more often preferred by farmers from the peripheral zones.

The higher production per unit and the cushion provided by other incomes have therefore combined to reinforce the monocropping of citrus crops in the central zones. Any movement away from water intensive crops in that locality is made still less likely by the relatively low cost of the resource to farmers. **Table 3** is an estimate of the cost of water by zone as a percentage of agricultural income. This is based upon the total income (current price for main crops by production level), and the water cost

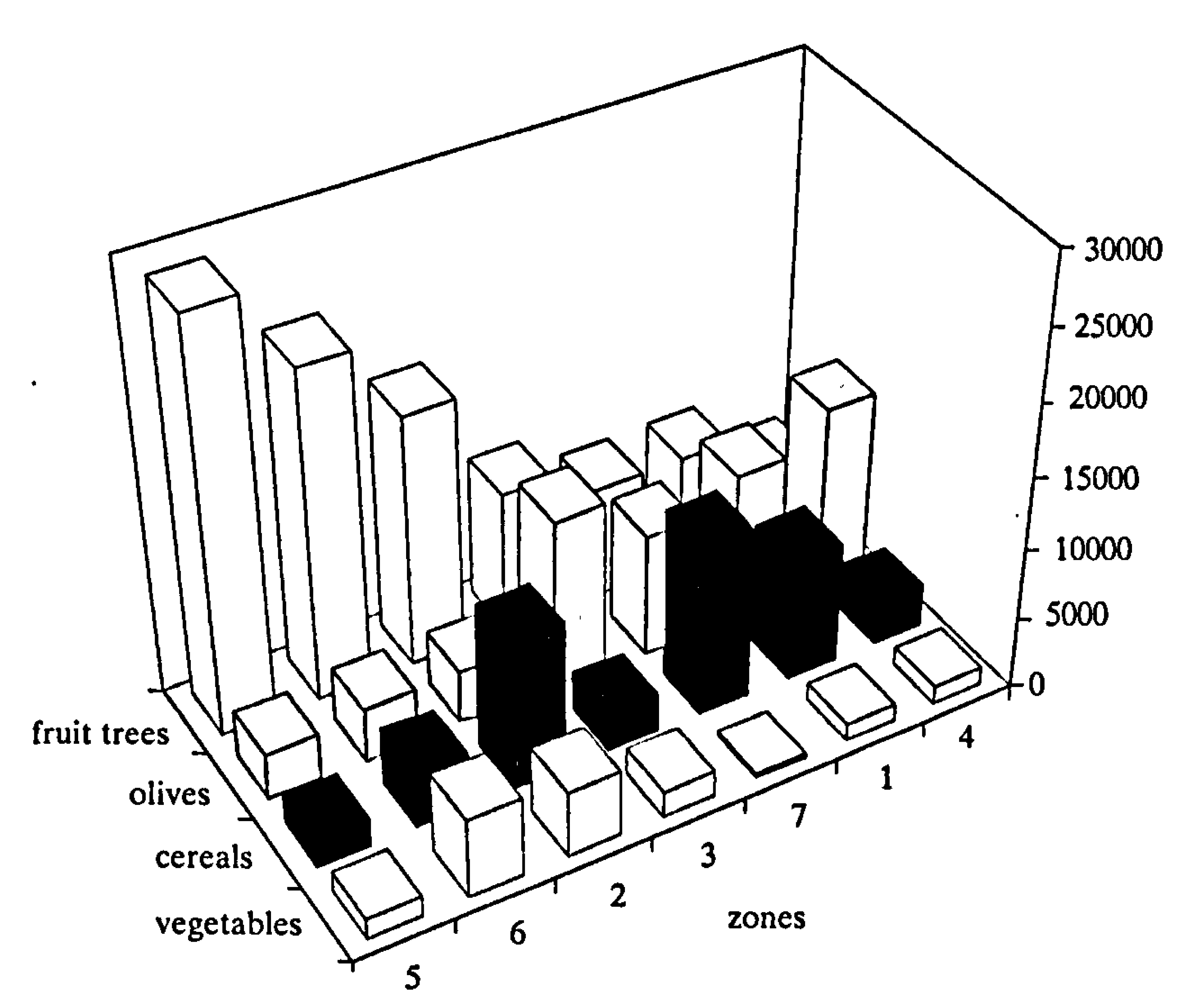

Figure 2 - Distribution of main crops by zone.

Table 2 *Variation by study zones.*

Zone	1	2	3	4	5	6	7
% Irrigated land	70	79	58	59	84	92	46
Oranges introduced	1969	1961	1965	1973	1952	1958	1969
Mean farm size (ha.)	5.7	4.7	8.9	6.5	4.5	3.5	7.2
Oranges/hectare (tonnes)	27	35	25	18	37	34	18
Mean price (kg) oranges	47	45	37	33	29	28	34

Source: Archaeomedes survey.

Table 3 *Variation in water cost: income between study zones.*

Zone	Income/str	Cost/str	% I/C
One	66613	6777	10
Two	86266	5112	6
Three	43231	10244	24
Four	38709	17589	45
Five	66515	5716	8
Six	77398	4664	6
Seven	35706	9890	27

([8]) Most of the citrus picking is undertaken by seasonal, migrant labour from Eastern Europe, although there has been an influx of Albanian workers in the 1990's. The local Gypsy population and mountain villagers have also traditionally supplied seasonal labour.

([9]) The farmers irrigate 4-5 times in a growing season. Pruning, pesticide and fertilizer application are not heavy labour commitments.

([10]) This inflexibility is reinforced by the unwillingness of farm children to enter farming and thereby provide the additional labour required for the production of more labour intensive crops. This is not the case in some of the peripheral zones where the children tend to enter farming directly from secondary school.

(bought water and bore hole costs - electricity and drilling), per stremma([11]). It clearly shows the differential cost of irrigated farming throughout the area with zones three four and seven having a far higher water cost to income ratio than the central zones.

Qualitative and quantitative degradation

A dramatic transformation has occurred in the visual landscape as a result of these crop changes, both in terms of the crops themselves (i.e. a blanket of fruit trees), and the visibility of the technologies in place to support their production([12]). The rapid expansion of sprinkler systems, in contrast to free flow irrigation, can be interpreted as a more «economic» approach to water use. In certain areas of the valley this reduction has been more than offset by the excessive use of sprinklers at night to protect against frost, an activity about which there is very little existing data([13]). Alongside this visual transformation has occurred a qualitative and quantitative deterioration of the water system. This has manifest itself in a number of ways:
In the peripheral zones (three, four and seven)

- The depth at which water is obtained has reached 400 metres plus in some areas.
- There has been an increase in the number of bore holes going dry.
- It has become more difficult to access water and the number of wells that are dry upon drilling has increased.

In the central zones (two, five and six)

- The quality of ground water has declined markedly with increased salination

The agricultural system has therefore entered a technological spiral, firstly for accessing water and extending the irrigated area and secondly for easing the impact of the resulting degradation. The most intensive and least diverse production has occurred in the central areas which also have access to the «Anavalos» canal infrastructure. This is not available to most of the peripheral area and as such covers that area which is suffering from salination rather than depletion.

The central zones also suffer from more acute problems of frost. This is countered in two ways, firstly through the use of sprinkler systems which draw upon ground water and raise the air temperature around the trees and secondly through the introduction of air mixers which disturb the air and prevent ice forming. The second part of the paper will now seek to explain some of these changes through the range of policy instruments that have impacted upon agriculture in the Argolid Valley.

Policy background

The field work undertaken in the Argolid identified three broad types of policy instrument that have influenced the emergence of agriculture in the area. These are inevitably linked, but essentially they relate to the farmer, to the crop and to the water system. The instruments originate from different levels in the policy hierarchy i.e. local regulations about the drilling of bore holes, national support for large scale infrastructure (the Anavalos canal system) and reduced agricultural electricity prices and European Union price support and subsidies for agricultural production.

Instruments focused on the farmer: management support

There are two forms of policy instrument which focus directly upon the farmer, the first provides management support and the second improved access to production technologies. Both have played a central role in the way that agriculture has developed in the Argolid. By management support is meant the provision of information, education and training and marketing. This will not be discussed at length here although two points can be made. Firstly the level of «on farm» support, or extension service, provided by the Service of Agriculture is perceived to have become infrequent and ineffectual.

«Nobody came from the Service of Agriculture to tell us about the programmes and what we need to do (to qualify). At the time subsidies existed but the agronomists were employed «policing» the «dumping of oranges» (Secretary of agricultural Co-operative).

A number of explanations can be provided for this. The two that are most prevalent refer to the increased administrative demands upon agronomists which have «tied» them to the desk and, less charitably, to the emergence of highly educated agronomists who do not wish to make contact with farmers outside of the office([14]). This has resulted in a situation whereby many farmers go to private agronomists for advice and has coincided with recent changes that have made the sale of pesticides the responsibility of licensed agronomists([15]). Inevitably this raises the possibility of a conflict of interests, which alongside the sale of fertilizers, could have negative effects upon the natural environment([16]). Both of the above points are encapsulated in the following statement by a farmer from the village of Pyrgella

«They (agronomists from the Service of Agriculture) offer no advice about the cultivations and we only use them to sign certificates. The dealers of pesticides do show an interest because they want to sell».

Marketing support

Although certain crops tend to be sold through particular markets (i.e. Oranges through co-operatives, olives through dealers, vegetables through local markets and vines for home consumption) these are not exclusive and where choice is exercised by farmers it is often determined by two central factors.

- The social formation of the farm household and the capacity to spend more time selling the crop at a higher price, this generally refers to the local markets (Athens, Argos etc.)([17]).
- The propensity of farmers to deal with risk and the willingness to forsake a lower guaranteed price for crops with price support in favour of the possibility of a higher price on the open market. The rejection of the former option also leaves the farmer exposed to crop loss through climatic uncertainty (frost) or virus and disease.

The key agencies in marketing support have been the co-operatives. These have

([11]) One stremma is approximately 1/10th hectare.
([12]) Bore holes, sprinkler systems and canal infrastructure for the distribution of spring water. Also the air mixers that are used in some areas to protect crops against frost are a distinctive feature of the landscape.
([13]) It is estimated that 10% of agricultural water is for frost protection (Allen et al., 1994).
([14]) Farm work, or work on the land, is often perceived to be of a low status. Equally office based work has a high status attached to it (De Waal, C., 1991), the combination of these factors may help to explain the perceived role played by public service agronomists.
([15]) Pesticides were previously distributed through the Agricultural Bank of Greece.
([16]) The excessive use of fertilizer has led to a concentration of nitrates in the ground water. This situation was exacerbated by the payment of a state premium to the fertiliser manufacturers. The level for this was determined by the amount of fertiliser produced however it was reduced in 1980 and removed in 1992.
([17]) There is a clear distinction between households that utilise the extended family to support farming activity and those who are reliant upon outside labour and therefore have less flexible marketing options. This also applies to the type of farming undertaken in that it often coincides with more diverse cropping.

evolved into their present form alongside the increased production of citrus fruits over the past thirty years. The original co-operatives were formed in the late 1940's to provide production and financial support to farmers. This role has been largely superseded by the marketing function undertaken today, particularly in response to the requirements of EU policy(18).

The number of members, and production levels, required to qualify for subsidy varies between Prefectures, i.e. The Argolid requires 100 members and 5,000 tonnes whereas Corinth only requires fifty members and a total production of 1,500 tonnes per co-operative. The scheme provides five year support for «start up costs» for groups of farmers producing fruit and vegetables. Legally formed groups of farmers are helped with the costs of management and administration, insurance, transportation of personnel and rent of buildings. The production related policy instruments to which the co-operatives respond are discussed below under crop support.

Technological support

Technological support refers to the improvement of access to relevant production technologies. A number of such policy instruments have helped to shape the agricultural system in the Argolid over the past thirty years. Between 1960 and 1980 the Greek Government provided subsidies of 20% for the installation of sprinkler systems and bore holes and for the purchase of farm machinery. These were subsequently taken over by the European Community(19).

Financial support has also been provided for the establishment of air mixers for the protection of crops, and trees, against frost. The first experimental mixers were installed in 1967 however the state supplied greater numbers in the mid 1970's, the mid 1980's and again in 1992. For the earlier mixers no contribution was required from the farmer and the operating costs were met by the Organisation of Farm Insurance (OGA). This has since been terminated and 25% of the total cost is expected to be met by the farmer(20). A 20% EC purchase grant is also available for those farmers, or more particularly, groups of farmers who require mixers but have not been in receipt of those distributed by the state. The nature of this distribution is inevitably contentious and is perceived as one example of inequity in local farming(21). More particularly the early distribution of subsidised mixers was seen to relate more to political allegiance than need and as such the requirement for a co-ordinated pattern of mixers to protect against frost was not achieved.

Two other significant sources of technological support can be identified over the past thirty years, the public electricity company (DEH) and the Agricultural Bank of Greece. The former have implemented a programme for farm electrification which provides advice about electrical installations (i.e. the size of bore hole pumps) and offers reduced electricity costs for on farm machinery and non-dwelling farm buildings(22).

In the period between the 1960's and early 1980's the Agricultural Bank of Greece was the main source of low interest capital loans to farmers. This supported much of the capital investment which underpinned the expansion of irrigated agriculture during this period. Loans have become much more difficult to obtain in the 1990's with farmers struggling to borrow money for the purchase of agricultural technologies which are becoming more expensive, both in unit cost, and in terms of meeting the demands made upon them as degradation becomes more extensive (i.e. the need for deeper drilling)(23).

The final form of technological support has been through the establishment of a canal infrastructure for transporting water from freshwater springs (Anavalos), which emerge into the sea in the south west of the area, to the central part of the valley. This infrastructure has been under development since the early 1960's and is perceived locally as something of a political football which has changed pace and course according to the priorities of the prevailing power base.

«We have been told that Anavalos will come to our village since 1981 but nothing has happened. Even if we want to bring it here ourselves they (the government) will not let us. It is used politically by PASOK and ND(24), everybody tells us that they will bring water». (Interview with village field guard)

Where farmers have good quality bore holes and Anavalos they tend to opt for the former as the source of their irrigation water(25). However when this choice does not exist (i.e. where the ground water is heavily salinated) then Anavalos will be used if it is available. This raises a number of issues. Firstly the option is not open to those around the periphery of the region who have suffered severe ground water depletion. Secondly, as degradation has increased local attention has focused more upon the need to expand the infrastructure than to encourage changes in agricultural practice likely to reduce water consumption. Thirdly the water from Anavalos has variable salt content which will exacerbate the problems of salination and require additional technological intervention in the form of acquifer recharge and the enforced leaching of salts from the soil.

Instruments focused on the crop

The main reasons cited by farmers for the emergence of less varied agriculture, although not necessarily for the expansion of irrigated land, are the internal support for production prior to the 1980's and, alongside the saturation of the internal market, the arrival of EEC price support and subsidies after accession in 1981. There are two forms of crop related policy instruments to take into account. The first is concerned with the level of price support made available for specific crops (i.e. oranges). The second is based upon subsidies that are paid to encourage changes in the existing crop balance. This is either in response to a diminishing market for a crop or alternatively to the presence of a disease or virus to which that crop is vulnerable.

Price support

Price support has been introduced since accession to the EC in 1981 and is a mechanism by which guaranteed prices are offered for specific crops. It is also perceived to be the source of greatest uncertainty for the majority of the farm-

(18) Regulation 1035/72 of the European Community provides the basic legal structure for most of the co-operatives in the Argolid.

(19) Subsidy for machinery under twenty million drachmas was paid under reg. 797/85 (superseded by 2328/91) and for projects above this figure reg. 1262. The larger subsidies were mainly for livestock units, fish farms and large greenhouses. Only the latter of these was taken up in the Argolid, and then infrequently.

(20) Air mixers cost approximately £20,000 to purchase with an additional £500-600 per year operating costs.

(21) It is possible for farmers with air mixers to extend the growing season and thereby to sell their produce after the peak picking season when prices are generally higher.

(22) The supported rate is approximately ten drachmas per kilowatt lower than the standard rate (of around twenty five drachmas) although this varies with the amount used.

(23) For example, the approximate cost of a new 200 metre bore hole is 6,000,000 drachmas or £18,000.

(24) The dominant political parties (Socialist and New Democracy)..

(25) Anavalos has a variable salt content, is rationed and paid for by units of time.

ing population. Support that is relevant to the Argolid mainly relates to citrus crops[26], although there is a complicated guaranteed pricing procedure for olive oil[27]. Unlike the majority of subsidies, which apply to individual farmers, this support is generally only provided when certain production criteria are met and representation is made through co-operative marketing structures. The negotiations regarding the full price for produce take place between the co-operatives and dealers who receive the subsidy from the EU[28]. An increasing number of co-operatives are now also operating as dealers.

The EU guaranteed price is central to farmers• decision making because it provides the benchmark by which they can estimate their income for the following year from citrus fruit. The price support paid for oranges extends to the dumping of excess fruit[29], to its use in fruit processing, particularly for juice[30], and to its distribution for welfare purposes (i.e. to schools in areas of special need).

Subsidy

Whereas price support is in effect a market guarantee, subsidies are a way of restructuring agricultural land use in response to concern about the market potential of a crop or its vulnerability to disease or a virus. Before accession to the EEC the Greek government subsidised the planting of new crops, mainly Merlin oranges, but also grapefruit, clementine and satsumas. Since 1981 a number of restructuring measures have been introduced. Some of these were designed to extend agricultural production through the year (i.e. the replacement of Merlin oranges with other citrus crops particularly Clementines). Other programmes were intended to uproot and replace existing crops:

- for which there was a reduced or inadequate market (i.e. the uprooting of vines and common mandarins)[31];
- that were vulnerable to disease or virus (i.e. the uprooting of the profitable apricot crop in response to the Sharka virus)[32].

The take up of subsidies for uprooting have generally been high[33], however, the second phase of these programmes which provide support for planting suggested replacement crops have often been less successful. A number of reasons have been cited in explanation of this.

- The crops may have been untried in the area and farmers are not prepared to •risk• their introduction. They have no •champions• (i.e. pistachio nuts were recommended as a response to the removal of apricot trees and had an extremely low take up)[34].
- The promoted crops may be perceived as more difficult to cultivate (i.e. early peaches and nectarines which do not keep and require immediate sale) and more labour intensive than existing crops such as oranges.
- There was a perceived discrepancy between the time scales for subsidising new crops and the length of time for them to reach maturity and a stable production. This was compounded by the inability to anticipate markets at the time the tree reached maturity and the subsidy terminated.
- Some promoted crops were felt to be inappropriate to the physical locality (i.e. the climate was perceived to be too dry for Kiwi fruits).

When the take up of suggested crops has been more successful it has tended to be with citrus crops (i.e. the replacement of Merlin oranges and common mandarins with other mandarin varieties such as clementines). This has had two significant and related effects. Firstly there has often been a weak correlation between replacement crops and the existence of a •real•, as opposed to an artificial or guaranteed, market. Secondly, and of particular relevance to the Argolid, has been the fact that the adopted crops have tended to be heavily water dependent and as such have exacerbated the degradation of that resource in the area.

Instruments focused on water

Until the early 1960's the aquifers which supply the bore holes of the area were adequately recharged by run-off from the perimeter hills and foothills. Demand for irrigation water was matched by this natural recharge. In consequence farmers have tended to regard land-tenure as conferring rights to this •renewable• beneath their land. The absence of any mechanism by which individual farmers could be made to take into account the effects of their decisions on the availability and quality of water in the future has been one of the principle factors underlying what are potentially very serious ecological and welfare problems. Two types of policy instrument have influenced water use, the first is indirect and has determined the price of water by influencing the cost of access. The second has focused upon the control or rationing of water to which that farmer has access.

Water pricing

At present the pricing of irrigation water is primarily through the costs attached to accessing water of variable depth, flow and quality. As has already been seen the costs of access to water are influenced by various forms of technological support. However there is no pricing mechanism which can relate to the farmers impact on the water resources. Similarly because it is a collective resource there is little incentive for farmers to reduce water consumption unilaterally.

Where a fixed price is attached to water it is invariably tied to restricted access through the canal system. Farmers, therefore, pay for a certain number of hours at a fixed rate and in some instances they can extend this period at a higher unit price[35]. Water pricing is also operated by arrangement between those farmers who have excess supplies and those who do not. The use of this water is often at night when the owner does not require it and payment may be in the form of cash or produce.

Water control and rationing

There are two main ways of controlling access to water, by regulating the amount of water that a farmer can draw, and/or restricting physical access to ground water. The former predominates in the highly salinated areas of the central plain where more water is obtained through the canal system. The latter form

(26) In 1992/93 oranges that were sold within the European community received 11 dr/kg support and those sold to •third• countries received 32 dr/kg.

(27) The price guarantee for olive oil in 1992 was approximately 120 dr/kg.

(28) One of the main concerns about the price support system was the uncertainty caused by the delays in payment from dealers to the co-operatives. The main market for oranges from the Argolid is Eastern Europe.

(29) If 30% of a co-operatives produce is exported then it is entitled to bury excess production. The standard price support is available and a two drachmas charge is levied at the havuza or dump.

(30) An EU premium of 28 drachmas per kilo is paid for juicing oranges. The factories purchase the fruit at 32 drachmas per kilo from the co-operatives (the standard rate of price support). 60-70% of building and capital costs are also available for the development or expansion of fruit processing factories.

(31) reg. 1196/3029 (1990) for uprooting common mandarins and reg. 1442 for the abandonment of vines.

(32) reg. 89/949 for uprooting the Tyranthas and Bebekou apricot plants. The EEC met 70% of the 640 ECU/stremma and the Greek government paid the remaining 30%.

(33) One of the main problems cited by farmers was the difficulty in obtaining information about the programmes.

(34) 150 ECU/stremma was provided to plant suggested crops in this scheme with a further 510 ECU per year for five years.

(35) I.e. Oranges may cost 3,000 drachmas per stremma for eight irrigations whereas vegetables will cost 3,750 for the same number. This is because the total number per annum for vegetables will exceed the threshold of twenty five irrigations.

of control is more in evidence in the peripheral villages where ground water depletion is the main concern and where there is no access to the Anavalos canals.

The physical access to ground water is controlled by the need to obtain licences for drilling or deepening bore holes. This is reinforced by the refusal of the electricity company to make the necessary electrical connection for bore hole pumps without the provision of a valid licence. No licence will be given for the drilling of a bore hole if it is within fifty metres of another. The effect of this has been to encourage the drilling of excessive numbers of bore holes as a precaution against the future loss of flow, or the salination, of those already operating. This restriction also fails to take into account the horizontal movement of the water under the surface and when excessive drilling does occur can result in the communication of salt between bore holes([36]). The small size of individual parcels of land in conjunction with this fifty metre restriction has meant that the most significant impact may well be in the ability of farmers to manipulate land values by drilling bore holes close to the perimeter of their land. Direct access to ground water can more than double the value of a parcel of land.

Recent changes in agricultural production across the Argolid valley as a whole have, therefore been inseparable from the irrigation technologies that have initially supported the expansion of irrigated agriculture and subsequently been used to counter the effects of a progressively deteriorating water source. This process has been underpinned by policy instruments that have

- provided a guaranteed income from water dependant crops,
- supported the organisational and capital requirements for the marketing and processing of those crops, and
- subsidised the technologies that are central to their production.

Of equal importance has been the way in which the costs and benefits of this process have been distributed within the area.

Conclusions and discussion

This paper has argued that agriculture in the Argolid valley has been shaped by policies that have contributed to a reduction in crop diversity and increased water dependency. These policies have taken the form of price guarantees for citrus crops that are heavy water users, technical support for accessing water and for remedial action in response to water degradation, and management support for the establishment of co-operative organisations that have focused upon the marketing of citrus.

Considerable qualitative and quantitative ground water degradation has been seen to result from these changes and it has been argued that the costs and benefits arising out of them have not been evenly distributed among the farming population. These factors have supported the emergence of a two tier farming system with the existence of a high proportion of part time citrus farmers in the valley. Farming is often a secondary occupation for this group and while they can adapt to reduced prices they are less able, or willing, to change the crops that they grow([37]). Elsewhere, full time farmers, or those for whom farming is the primary source of income but who have to supplement it with other work, have continued to grow more diverse crops with greater labour requirements([38]).

Water reduction, equity and the introduction of policy

It has been argued that farm related policy for the Argolid must encourage the reduction of water use and a more equitable distribution of the costs and benefits among the farming population. Any intervention must account for the spatial context in which production occurs i.e. the complete uprooting of orange trees would not account for the fact that a certain number can be efficiently grown in combination with other crops. It is essential, therefore, to identify those areas that are most conducive to a particular crop and to acquire a better understanding of the social context under which change would be adopted i.e. what information and support is required by farmers? (Lemon and Park, 1993). Similarly, policies must address the process by which they are implemented as well as their overall objective. Therefore, support must be available for both the substantive costs of transition and the administration of the process. For example, the difficulty of obtaining information from the public administration has been seen as a significant constraint by many farmers.

Uprooting orange trees: a policy option for agriculture in the Argolid Valley?

Because of the variation in social, economic and natural conditions within the area a package of policy instruments would need to be considered to reduce water use while supporting equitable production options. The uprooting of a proportion of the orange crop is the most obvious way to reduce levels of irrigated agriculture and thereby slow down soil and aquifer degradation. Questions then arise about what land should be taken out of orange production and what should be done with this land?

The payment of an additional premium for «set aside» (Potter and Gasson, 1988) would reduce water consumption. However, if this was lower than the potential for generating income from more sustainable cropping practices (i.e. cereals([39]), olives([40]), then uprooting payments would encourage «authentic» farmers to adapt and continue farming while supporting the removal of those who are less flexible, farm as a secondary occupation, and tend to mono-crop citrus fruits. In addition those farmers who continue to grow citrus crops would have access to a wider market, particularly in the local free market. This would reduce the dependency upon price support which could be lowered incrementally and subsequently removed.

A number of other conditions could be incorporated into this package.

- Uprooting should be by the tree - approximately forty five per stremma and at least four years old - and not by area. This would discourage new planting and in conjunction with reduced price support would provide some backing for those who planted prior to the introduction of the restructuring policy.
- The level of subsidy for uprooting

([36]) Isolation techniques are used to prevent this transfer, however, if one bore hole is not isolated or is inefficiently isolated then the surrounding holes are vulnerable to salt intrusion.

([37]) Many of these farmers have business interests outside of agriculture (i.e. property development) or professional occupations (teachers, lawyers etc.)

([38]) This group are perceived locally as «authentic» farmers.

([39]) Hard wheat forms the base for local bread. It is, however, only occasionally grown and usually on poor quality soil producing 150 kilos/stremma. With improved soil conditions, through regeneration and expansion to better soils currently used for citrus production, this could rise to 500 kilos. With improved marketing and local economies of scale (co-operatives) the additional production could be sold to local bakeries.

([40]) The production of olives requires very little water and far less fertilizer and pesticides than citrus trees. However, the market for olive oil is limited in Northern Europe and that which does exist is dominated by Italian produce. Retail prices are also very high. It would therefore be necessary for temporary crop support to be introduced alongside marketing initiatives (i.e. related to issues of health) to underpin production while the market is expanded.

could be adjusted according to the dependence upon ground water sources of irrigation. Lower payments could, therefore, be made in those areas that have access to other irrigation sources.

These criteria would reduce the dependence upon artificial markets for water dependent crops, would encourage the use of non-ground water irrigation sources where they are available and the adoption of crops with lower water demands where they are not. Incorporated within this policy package would be marketing and organisational support for farmers and subsidy for irrigation technologies which are less heavy water users (i.e. drip irrigation). This would be based upon an improved understanding of the farming agenda and the conditions that need to be in place to encourage agriculture that is less water dependent.

Therefore in conclusion, the socio-economic and natural characteristics of the Southern Mediterranean have historically generated an agricultural system which produces a wide variety of crops at yields considerably below those of Northern Europe. Attempts to restructure agricultural production according to criteria of technological and economic efficiency without paying sufficient attention to social and ecological factors has resulted in the removal of options from many farmers. This has manifest itself in several ways; through the loss of agricultural diversity, the increased degradation of natural resources and the inequitable distribution of costs and benefits among the farming population. ●

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Environmental degradation and intensive citrus production in the Argolid Valley, Greece ?(1)

Mark LEMON, Condylenia BLATSOU*, Roger SEATON**

RÉSUMÉ

Les milieux sociaux et physiques contemporains sont le produit de leur histoire et de leur localisation. Cela ressort invariablement de l'interrelation entre activité anthropogénique et systèmes naturels à des échelles locales et plus vastes. La vallée de l'Argolide, en Grèce, représente couramment un milieu physique que l'on voit se dégrader rapidement par suite d'une agriculture irriguée intensive. On constate une répartition très variable des coûts et bénéfices au sein de la communauté rurale. Cela s'explique par l'impact des diverses combinaisons de facteurs physiques, politiques, économiques et sociaux sur les décisions agricoles locales. Un certain nombre de types d'exploitations fermières sont distingués et considérés selon les options agricoles dont ils disposent dans le futur.

ABSTRACT

Contemporary social and physical environments are products of both their history and their location. Invariably, this emerges from the reciprocal relationship between anthropogenic activity and natural systems at local and wider scales. The Argolid Valley in Greece is used to represent a physical environment that is seen to be degrading rapidly as the result of

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intensive irrigated agriculture. Considerable variation in the distribution of costs and benefits within the farming community is identified. This is explained by the impact that various combinations of physical, political, economic and social factors have had upon local agricultural decisions. A number of farming types are distinguished and considered in terms of the future agricultural options that are available to them.

It has generally been accepted that a major, if not the major, source of insight into the present lies in a comprehensive understanding of the past. Central to this understanding has been an increased recognition of the need to interpret the process of change as a restructuring which is location-specific and based upon a « seamless » interaction of human and natural systems (Wolch, Dear, 1989 ; Lovejoy, Napier, 1988 ; Redclift, 1994). This is not a call to return to the idiosyncratic community studies which dominated much social science in the late 1960's and 1970's and which tended to study localities for their own sake (Stacey, 1969). Rather, it reinforces the need to obtain data about social and physical change, for which the locality is the appropriate unit of analysis (Newby, 1986).

Implicit within this approach is a recognition of the fundamental relationship between space, social process, and capital (Massey, 1984) or social and systemic integration (Giddens, 1984). According to Giddens, systemic interaction occurs in the absence of the individual and is temporally and spatially diffuse. The interaction or « reproduction » is essentially between political and capital institutions, and the local outcomes of that reproduction are not likely to be accounted for. Social interaction, however, occurs between individuals in response to this structural activity and changes in the local social and physical environment.

> « What is required, then, is a conceptual framework which does not lose sight of the reciprocal relationship between localised and wider scale social (and natural) processes ». (Cox, Mair, 1989).

This framework must also acknowledge that the role played by the physical environment is often socially produced and socially reproducing (Urry, 1987). For example, the social and economic groupings that develop in response to the demand for seasonal labour to pick oranges, and the need to market the produce through co-operative structures, are inseparable from the conditions that determine the productive potential of the land. At the same time, the act of working the land changes its future capacity. The movement towards water and soil degradation in the Argolid Valley, as a result of intensive irrigated farming activity, provides one example of this. The Argolid study drew upon this conceptual framework :

1. to provide resilience oriented policy directives for sustainable development and resource management in the area ;

2. to elicit the perceptions of key actors about the environment, farming practice and policy instruments and to evaluate existing policy and its delivery in order to contribute to the design of remedial and preventative policy (Allen *et al.*, 1994).

Understanding local agendas

The pursuit of these objectives raises key issues for an improved understanding of the dynamics of local environmental change. Firstly, there is a need to improve our understanding about how different anthropogenic structures and processes affect and are affected by the natural system and, related to this, how the variation in agendas, both within and between agencies, can provide an insight into decision making about the management of natural resources (Lemon, Park, 1993). Butzer (1994) addresses this from a slightly different perspective in his discussion of the Islamic traditions of agro-ecology. He is aware of the central role that can be played by farmers as sources of local data. This reinforces the belief that : « *agricultural innovation is not a faceless process, but part of an intellectual confrontation with problems and prospects discussed among individual people in the bar and in the home. – Why did farmers in some places and at some times practice either conservationist or exploitative agriculture ?* » (Butzer, 1994 : 8).

Butzer focuses upon the « agronomic tradition » which was « grounded in the experience and understanding of the common farmer ». It is, therefore, necessary to identify the range of factors that influence farming decisions.

Social enquiry and natural phenomena

The second issue refers to the problems of obtaining data which are of sufficient definition to be useful but at the same time capable of providing an insight into the variation within the system under study, both through time and across space. This is particularly relevant to the measurement of physical phenomena where data about the natural system are often of a high level of definition but very localised in time and/or space (Lemon *et al.*, 1994).

The insights that can be gained from social enquiry do not only refer to the agendas of local populations, and the decisions and activities that they pursue on the basis of these, they can also inform us about changes in the natural system. Farmers have a reasonable idea how much water they use ; they know, its distribution throughout the year and approximately how much salt is present. It is possible, therefore, to obtain a comprehensive overview about a range of natural systems and their interactions that would not be feasible, for reasons of finance, personnel and accessibility, by using « hard » scientific techniques at a far higher and, possibly, unnecessary level of resolution.

The field work for the study addressed these issues in two phases. The first involved thirty semi-structured interviews with farmers, agronomists, academics and politicians active in the area. These were intended to elicit the salient perspectives and agendas concerning agricultural land use. They provided the basis for a more structured second phase of interviews with over two hundred farmers[(2)], which concentrated upon farming behaviour with respect to crop production, income generation and markets, and the use and costs of water resources. The range of data and data sources for the study is shown in table 1.

Data type	Source
Climate and hydrology	
Rain, temperature, evapotransperation	Meteorological Service
Changing microclimate	Interviews, public meetings
Salinity data for springs	Agricultural University of Athens
Salinity data for irrigation water	Interviews
Aquifer pressure	Agricultural University of Athens (AUA)
Bore-hole pressure	Interviews, AUA
Bore-hole location, history	Interviews
Irrigation requirements for crops	Interviews, export agronomic opinion
Agricultural water use	Interviews, AUA
Production land use	
Agricultural development/land use	Service of Agriculture, Interviews
Expansion of irrigated area	Service of Agriculture, Interviews
Crop change and production	Interviews, Service of Agriculture
Crop prices	Interviews, Co-operatives
Demographic, Social, Political Agency	
Occupational structure, demography	Interviews, Greek Statistical Service
Levels/form of Public Administration	Interviews
Identification of key agencies	Interviews
Relevant policy instruments	Interviews

Table 1. Data collected and source.

The dimensions of farming opportunity space

The data in table 1 were collected as part of an integrated method to represent localities as an « organic whole » (King, 1989), by establishing under what combinations of factors, and at what scales, those localities are (re)configured. It is this improved understanding of the relationships within a « messy » system that can provide a more useful insight into the range of options available to people. Therefore, we are dealing not only with the interrelation between human and natural systems and how they differ hierarchically, but also with how they determine local variance.

Table 2 conveys the socio-economic and physical dimensions that have emerged out of the fieldwork and represents the basic attributes which, under various confi-

(2) This was approximately 10 % of the farming population across the area.

gurations, determine the options that are open to farmers across the region. The term dimension has been chosen specifically to represent a range within each attribute (i.e. from high status attached to farming to the work being held in low social esteem) as well as the possible combinations between them.

Socio-economic dimensions	Physical dimensions
Reliance upon, use of seasonal labour Personal/Family activity on farm Capital investment in agriculture Labour : Technology ratio on farm Social acceptability of farming Entry of children into farming Role of extended family in farming Level of hidden investment (Labour) Adoption of local, external markets Level of self-sufficiency Variety of crops grown	Soil quality Topography Microclimate Availability of water Quality of water Productive level of crops Crop vulnerability
Economic organisation	**Information-public administration**
Price support and subsidies Efficiency of marketing organisations (co-operatives, local market activity) Water and technology prices	Level of infrastructure Effectiveness of agricultural extension service Patronage-political involvement

Table 2. Socio-economic and physical dimensions of farming opportunity space.

These dimensions will provide a basis for the rest of the paper which will look at the transformations of agriculture over the last fifty years for the Argolid Valley as a whole. The variance within the system will then be discussed, and a number of farming types identified and considered in terms of the emergent options for agricultural change in the area.

Background to agricultural change in the Argolid

The Argolid Valley is situated in the Argolis region of the North-Eastern Peloponnese in Southern Greece (fig. 1). The total catchment (approx. 1 100 sq. km) is divided into 38 600 ha mountains, 26 500 ha hills and 42 000 ha valley. The valley itself is divided into 29 500 ha cultivated land, 7 800 ha pasture, 3 000 ha. urban surface and 1 750 ha uncultivated land. The soils of the valley are deep (silt, loam and clay) and fertile, whereas those of the hillside are stony and of poor irrigability.

The climate of the area is predominantly Mediterranean with temperatures ranging from minus 5 °C in January to plus 40 °C in the summer months. The temperature away from the sea is approximately 2 degrees lower. Mean rainfall for the area is over 500 mm and is usually recorded within 90 days (throughout the year). These

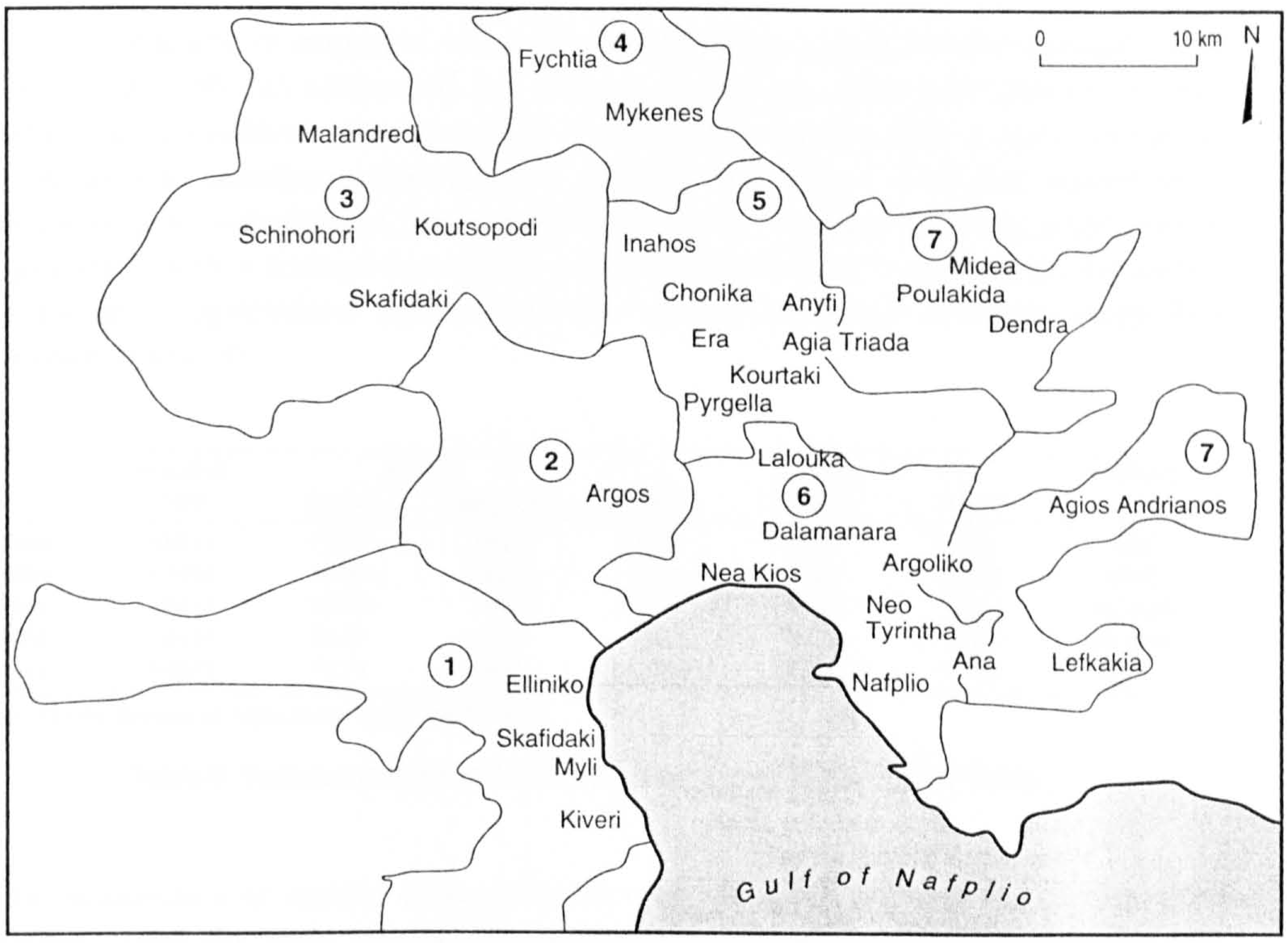

Fig. 1. The Argolid Valley with study zones.

factors lead to a 75 % relative humidity in the winter (when there is most precipitation), with the result that levels of frost vary considerably(3).

The area is dominated by agriculture with 50 % of the working population involved in farm work of some form although many of these have other sources of income(4). Agriculture is also the main consumer of water in the area, using approximately 140 million m^3 of water (89 % of the total), compared with 10 million m^3 for drinking water and less still for other industrial users (Argolid Association of Agronomists, 1992).

Production, technology and degradation

The use of irrigation water has increased markedly over the last fifty years. Before 1940, there were 4 000 ha of irrigated land, compared with over 20 000 ha

(3) The problem of frost is perceived by many local farmers to have become far worse as the area of irrigated trees has increased.

(4) Greek Statistical Service.

today. The majority of irrigation water is obtained from ground water through wells and bore holes (95-125 million m^3 per annum, dependent upon precipitation levels). An additional 25 million m^3 is acquired from springs via specially constructed pumping plants and distributed through the plain by aqueducts. This has supported a move away from subsistance, and predominantly dry, farming (cereals, vines, olives and grazing), with a limited amount of irrigated production (vegetables), towards a more intensive, specialised and less diverse agriculture based primarily upon fruit production (table 3).

	Irrigated	Arable			Trees		Tobacco
	Total	Cereal	Vegetable	Citrus	Orange	Olive*	
1960	15914	18933	5809	6862	5041	1783	3641
1964	17155	16464	5002	8119	6487	2449	4676
1972	17414	10961	3846	10452	8356	2600	no data
1980	18045	9469	3173	9482	7469	2885	no data
1986	19079	7174	2887	10784	8733	2852	2334

Source : Greek Service of Agriculture. (*per 1 000 trees).

Table 3. Surfaces planted with the main crops grown in the Argolid Valley.

The dominance of certain crops over the past 40 years is not only a recent phenomenon : until the early part of this century the area was dominated by vine growing, more for sultanas as a cash crop than for wine, which was consumed at home. This system collapsed with the combination of falling prices and the arrival of *Perenospora*, which destroyed many of the plants. The vulnerability of monocropping, or restricted cropping, to pests and disease has been an important factor in the shaping of local agriculture. More recent examples are the demise of the lemon production as a result of frost and *Coryphoxera* in the 1960's and the *Sharka* virus in the 1980's, which destroyed the apricot trees.

The destruction of a crop is seldom attributable to one cause (i.e. a virus or price drop) because adaptive mechanisms will invariably emerge to counteract this by raising the price of the remaining, non affected, crop, or through more intensive production to maintain income levels. It is, therefore invariably a combination of unpredictable factors that will ultimately threaten the cropping system. Table 4 is a summary of the main factors which influence the production of the predominant crops currently grown in the Argolid Valley. This relates closely to many of the dimensions outlined in table 2.

A number of other factors must be taken into account to provide a satisfactory explanation of crop choice. For example, crops that can only be sold through the local markets (Argos, Nafplio or Athens) inevitably require greater time commitment from the farmer or members of their household. Similarly, crops that have a high labour content, such as vegetables, can only be grown by those farmers who do not have major occupations outside of farming. With the exception of the picking season in the new year, oranges, by comparison, have a low labour content. These

Crop	Physical conditions	Labour : technology ratio	Market/price	Vulnerability	Water requirements
Orange	Loam sand, low humidity, not too steep	Low seasonal labour input, air mixers, sprinklers, isolation against salt	Overseas (Co-op), supported prices lower local market 40-70 dms/kg	Bad frost, excessive salt, long shelf life	300-400 tns/str/yr. in hills, 100-150 in valley with sprinklers
Apricots	Good drainage, high organic content, not too steep	Higher labour content than oranges, use of sprinklers to irrigate	No supported prices, loss of overseas market with Sharka. 70-250 dms/kg	Sharka (1980's) destroyed main Bebekou and Tiryntha varieties	High, up to 500 tns/str/yr
Lemons	Good drainage, not heavy soils, not too steep	Higher labour to protect crop	Highest price of citrus crops	Very sensitive to frost, salt and Coryphoxera virus	Simular to oranges but must be good quality
Olives	Usually grown in poorer quality soil, on slopes	Low labour and technology. Often migrant pickers	Subsidy (approx. 120dms/kg, 550 dms/kg oil (8 kg of olives)	Dacus Olea (insect) sprayed against	Seldom irrigated, (One kg of corn oil takes 40 kg water)
Vines	Prefer high calcium, will grow on hillside	Hight labour input (household based)	Subsidies have ceased apart from uprooting (EC 1442)	Phylloxera and Peronosporos	Seldom irrigated, if they are then sprinkler systems are used
Vegetables	Flat, rich in organic matter	High labour input, (household based), particularly for tomatoes	Self and local consumption (Argos, Athens)	Excessive salt (apart from lettuce, artichokes etc.) Lack of water	Often high, approximately 3 000 tons per stremma for tomatoes
Cereals	Wherever there is empty land	Household labour	Seldom sold (home consumptionn) ; if it is, 50 dms/kg Subsidy 4 500 dms/stremma	Extremes of rain and wind	Rain irrigation

Table 4. Summary of crop characteristics.

points will be returned to below with reference to the spatial differences in agricultural production.

A dramatic transformation has, therefore, occurred in the landscape of the area as a result of these crop changes, both in terms of the crops themselves (i.e. a blanket of fruit trees) and in terms of the visibility of the technologies in place to support their production[5]. Table 5 provides an insight into the increased use of basic technologies and highlights the potential for increased irrigation.

	Pumps*	Sprinklers	Tractors
1964	2953	3	691
1972	4535	20	1490
1980	6792	1159	2933
1986	8393	5031	3279

Source : Greek Service of Agriculture (*Electric pumps for bore holes)

Table 5. Increase in selected technologies.

The rapid expansion of sprinkler systems, in contrast to free flow irrigation, can be interpreted as a more « economic » approach to water use. However, in certain areas of the valley, this has been more than offset by the use of sprinklers at night to protect against frost, an activity for which there is very little existing data (see Allen *et al.*, 1994). Alongside this visual transformation has occurred a qualitative and quantitative deterioration of the water system, which has manifested itself in a number of ways.

- the depth at which water is obtained has reached more than 400 m in some areas ;
- there has been an increase in the number of bore holes going dry ;
- it has become more difficult to access water ; the number of wells that are dry upon drilling has increased ;
- the quality of ground water has declined markedly with increased salination ;
- the agricultural system has become dependent upon technology, firstly for accessing water and extending the irrigated area and secondly for easing the impact of the resulting degradation.

The recent reduction in agricultural diversity for the area has been mirrored by that for industrial activity. Prior to the 1930's, cotton, silk and wool products were manufactured as well as leather for shoes, alcohol, pasta and olive oil. There were

(5) Bore holes, sprinkler systems and canal infrastructure for the distribution of spring water. The air mixers that are used in some areas to protect crops against frost are also a distinctive feature of the landscape.

also timber and iron factories in Argos and a considerable amount of tobacco production. Only the oil extractors and, to a greatly reduced extent, tobacco processing remain as features of the industrial landscape. Where new industrial processes have been introduced or existing ones expanded, they concern almost exclusively fruit processing, either for juice or canning[6]. As a consequence, they reinforce the existing monoculture and thereby the reliance upon water dependent crops.

There has, therefore, been a progressive standardisation and degradation across the area as a whole. The extent of this degradation, the form that it takes (i.e. salination, water depletion), and the perceived distribution of costs attached to it, vary considerably. Consequently, it is necessary to look at the disaggregate as well as the aggregate picture.

Disaggregation and zones

In order to produce a picture of the variation within the study area, considerable time had to be spent in the development of a zoned structure which represented soil, hydrological and topographical characteristics, as well as climate data and crop production figures. The need to adopt contiguous zones for modelling purposes and the different spatial structure of the various attributes made it particularly difficult to identify zones that retained the integrity of each attribute (Allen *et al.*, 1994).

What was sought was a pattern, or configuration, of attributes that approximated the physical and production system of the area. It was felt that the best way to achieve this was to draw upon local expertise through a series of extended interviews with agronomists[7]. The agreed zones are shown in figure 1 and were broadly supported by subsequent analysis of cropping and water use data.

A number of general observations can be made about this zoning structure. Firstly, the problems with salt and frost predominate in the eastern part of the valley, whereas the peripheral areas have greater variation in their cropping and more difficulty in obtaining water. With the exception of zone one, the soils are generally poorer as one moves away from the central plain, with an inevitable increase in slope and the related problems attached to drainage and water conservation.

Distribution of crops

The zoned structure conveys an increase in monocropping as one moves to the plain and a more diverse production system as one moves away from it. Figure 2 clearly shows a distinction between the three central zones (two, five and six) and

(6) Capital support for this has been forthcoming from the European Community and highlights the disparity between the agendas of economic development, agriculture and the environment.

(7) The interviews lasted a total of approximately eight hours.

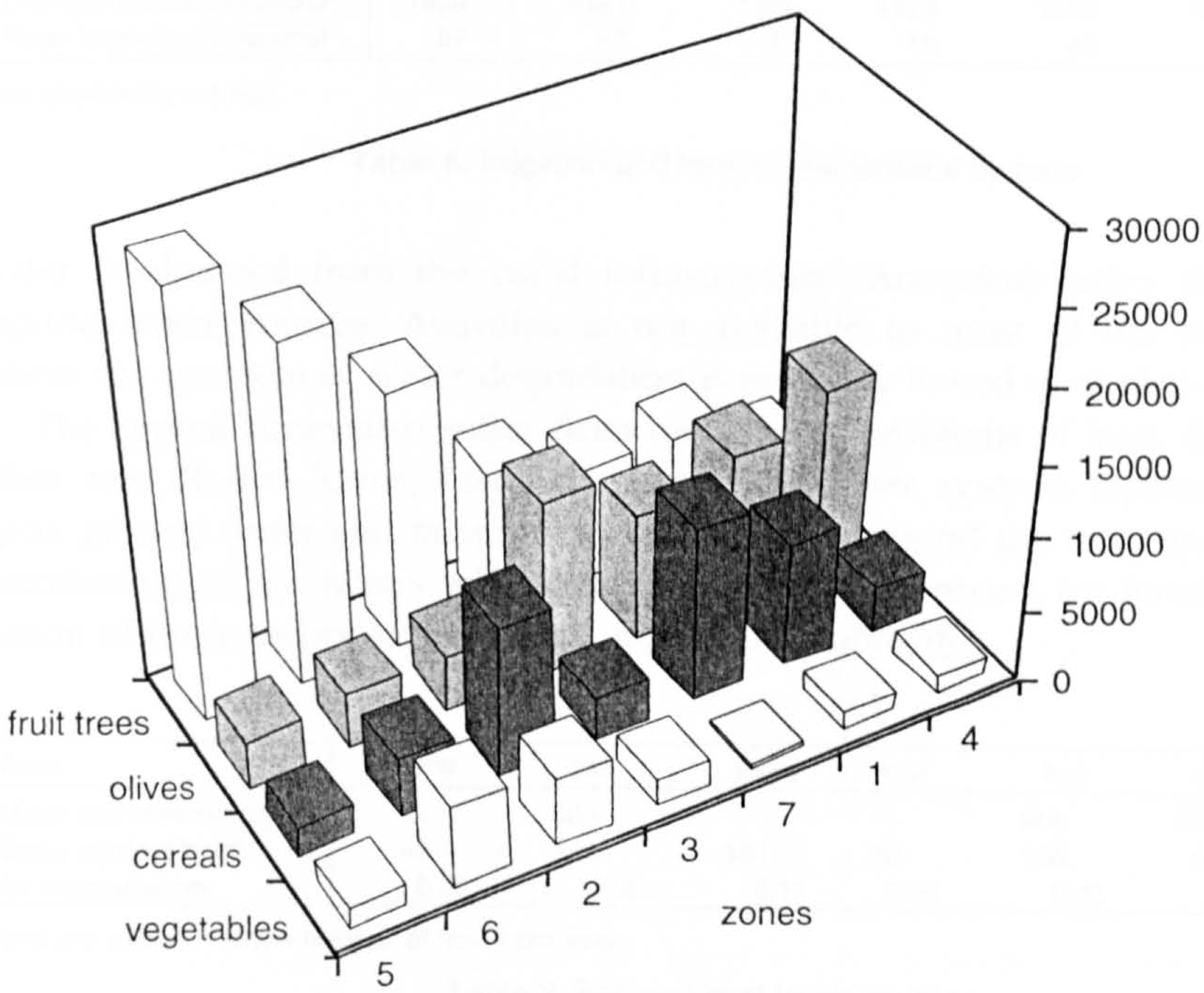

Fig. 2. The distribution of main crops by zones.

the outer zones. Zones five and six in particular are dominated by irrigated fruit production with more vegetables grown in zones six and two. The remaining zones have greater variation in crops with a far higher proportion of dry farming. The cereal production in zone two is higher than would be expected ; this is grown in the western areas, away from the plain, where a more mixed farming is undertaken.

Costs and benefits

It is possible to link the current spatial distribution of irrigated agricultural production to its temporal emergence by considering the approximate dates at which specific irrigated crops were planted across the area. For example, table 6 shows a noticeable movement away from the central valley to the periphery of the area for the introduction of oranges. This coincides with the percentage of irrigated land and is inversely correlated with the size of farm(8).

Ground water degradation also shows a marked spatial pattern. The water in zones five and six is heavily salinated (table 7). As a result, most of the irrigation

(8) The larger farms in the outer zones correlate with extensive, dry farming activity on poor quality land.

Zone	one	two	three	four	five	six	seven
% of irrigated land (1990)	70	79	58	59	84	92	46
Oranges introduced (mean)	1969	1961	1965	1973	1952	1958	1969
Mean farm size (stremma)	57	47	89	65	45	35	72

(Ten stremmata = 1 ha).

Table 6. Irrigation and farm characteristics by zone.

water is obtained from the canal infrastructure (Anavalos) rather than from local ground water sources. Anavalos is not available to most of the peripheral area, where the problem of water degradation is primarily linked to depletion.

The central zones also suffer from more acute problems of frost. Remedial action takes one of two forms, firstly the use of sprinkler systems (sprays) which draw upon ground water and raise the air temperature around the trees and secondly the introduction of air mixers which disturb the air and prevent ice forming. The distribution of these technologies is also indicated in table 7(9).

Zone	one	two	three	four	five	six	seven
Mean salt content (ppm)*	71	881	-	-	966	835	400
Spray against frost**	49	142	101	70	138	69	31
Air mixers/farmer	0.00	0.14	0.11	0.00	0.33	0.31	0.26

*Parts per million ** Mean number of hours per year.

Table 7. Salt and frost levels by zone.

The money for the construction of the Anavalos canal system, and for payment for many of the air mixers, has come from central government and the European Community. This is perceived by some farmers as an example of the inequity which exists between those who farm the central areas and those who are on the periphery. This is also felt to extend to income generation, which is affected in two main ways, through the variation in productive capability and the ability of farmers to deal with fluctuating prices. Table 8 shows a far lower orange production per unit of land in the peripheral zones. This is due partly to natural phenomena such as poorer soil, stony ground, and slope and partly to the lack of subsidised remedial technologies and the increased costs of drilling more deeply, and frequently, to counter the problem of water depletion (Allen *et al.*, 1994 : 131-133).

The mean price per kilo of oranges is also considerably lower for zones five and six, where the main citrus producers and the least diverse farmers are. To understand this apparent paradox, it is necessary to look at the relationship between crop and market characteristics and the farming structures in place to produce and sell.

(9) No official data exists about the extent of this activity, but the current research estimates that between 10 and 30 % of total water use in some areas is for protection against frost.

Zone	one	two	three	four	five	six	seven
Mean production tons/str.	2.7	3.5	2.5	1.8	3.7	3.4	1.8
Mean price per kg	47	45	37	33	29	28	34

Table 8. Production of, and price for, oranges by zone.

As has already been seen, with the exception of the picking period[10], oranges are not labour intensive[11]. Consequently, the monocropping of citrus has emerged alongside a pluriactive farming community (Arkleton Trust, 1988). This has provided a supplementary income for many land owners with other « primary » occupations[12] and is noticeably different from other forms of multiple job holding that have been forced upon farmers as a result of difficulties in generating sufficient income from the land (Damianos *et al.*, 1991). The latter model has been more prevalent in the peripheral zones, particularly zone four around Mykenes. Two important points arise out of this which help to explain the difference in mean price per kilo for oranges.

- The dependence upon citrus production in the central plain is reinforced by the high proportion of part-time farmers who are unable to farm in a manner which is more time consuming than that required for the production of citrus fruits[13].
- These farmers are less likely to have the time, or the inclination, to sell their produce at local markets, albeit for higher prices, than can be achieved through the co-operatives and the supported price system. The adoption of local markets for citrus, in conjunction with other crops, is often preferred by farmers from the peripheral zones.

The higher production per unit and the cushion provided by other incomes have therefore combined to reinforce the monocropping of citrus in the central zones. Any movement away from water intensive crops in that locality is made still less likely by the relatively low cost of the resource to farmers. Table 9 is an estimate of the cost of water by zone as a percentage of agricultural income. This is based upon the total income (current price for main crops by production level) and the water cost (bought water and bore hole costs – electricity and drilling), per stremma. It

(10) Most of the citrus picking is undertaken by seasonal, migrant labour from Eastern Europe, although there has been an influx of Albanian workers in the 1990's. The local gypsy population and mountain villagers also supply seasonal labour.

(11) The farmers irrigate 4 to 5 times in a growing season ; pruning, pesticide and fertilizer application are not heavy labour commitments.

(12) Many of the citrus farmers in the central zones are professional people or have primary business interests outside of farming, particularly in property, both locally and in Athens.

(13) This inflexibility is reinforced by the unwillingness of farm children to enter farming and thereby provide the additional labour required for the production of more labour-intensive crops. This is not the case in some of the peripheral zones, where the children tend to enter farming (Allen *et al.*, 1994 : 74-96 ; De Waal, 1991).

Zone	one	two	three	four	five	six	seven
Mean income/str.	66613	86266	43231	38709	6515	77398	35706
Cost of water / str	6777	5112	10244	17589	5716	4664	9890
% Income/Cost	10	6	24	45	8	6	27

Table 9. Variation in water cost : income between zones.

clearly shows the differential cost of irrigated farming throughout the area with zones three, four and seven having a far higher water cost to income ratio than the central zones.

Conclusions : farming types and future options

This paper has described the rapid expansion of irrigated agriculture in the Argolid Valley over the last 40 years. This has coincided with an increase in price support for some irrigated crops, standardisation of cropping and an increased emphasis upon higher unit production. There has also been a qualitative and quantitative degradation of ground water resources with the result that a technological dependence has developed both for remedial action(14) and to enable the continuation of existing agricultural practice(15).

Table 2 identified a range of perceived dimensions that have been configured in various combinations and over a range of temporal and spatial scales to determine the pattern of agricultural change in the Argolid Valley. These changes were then considered in terms of the area as a whole and, using a simple zonal structure, of the variation within it. It is possible to estimate the range of crops that could be grown in the area by looking at the characteristics of those crops and matching them to the configurations of physical attributes that determine natural locations. This procedure can then be extended by taking into consideration the ability of various technologies to intervene and modify the natural environment in those locations. It is conceivable, therefore, that a number of « option spaces » could be developed which represent the range, and balance, of crops that can be grown in different localities, at different levels of intensity, and with a corresponding range of impacts on the natural resources.

This « physical » option space obviously fails to account for the decisions of farmers, which are made with only partial reference to the physical characteristics of the crop or the physical attributes of a locality. Similarly, while the limited economic potential for a crop may well constrain its adoption, the existence of such potential does not guarantee that (a) farmer(s) will choose to grow it.

(14) Attempts have been made to replenish the aquifers from the fresh water springs which supply the Anavalos canal system.

(15) For example, through the introduction of increasingly sophisticated drills and pumps that are capable of obtaining water at depths of 400 m.

It has been argued that an improved understanding of the range of farming agendas must be established alongside the physical and technological data that is invariably used to support policy formulation. The integration of this data has led to the development of a provisional set of farmer types differentiated by the land they farm, the way they farm it, and the socio-economic make up of their households. This latter category extends to incorporate the prevalent attitude towards farming within the household. The adoption of this typology provides an initial insight into how different groups of farmers might respond to a range of future options. Four types of farmers were identified in this initial classification. These should be considered alongside the physical dimensions that have already been discussed in the paper.

1. This group is predominantly situated in zones 5 and 6 : there is monocropping of irrigated citrus crops with high unit productivity and the adoption of price support system rather than local markets(16). A high level of technological support exists to offset the effects of degradation. Primary employment and investment are outside of agriculture, and the ability to farm in a more diverse way is constrained by limited family commitment to working the land. The low status accredited to farming within this group is further exemplified by the tendency for farm children to enter higher education and move into occupations other than farming.

This group has a high price elacticity due to the existence of second incomes. They are thereby able to withstand price reductions and are less vulnerable, in economic terms, to degrading natural resources.

2. Zones four and seven have larger farms with limited crop variety and low levels of technological support to offset the effects of degradation. There is low productivity due to water degradation and poor soil. Farmers are constrained by the need to generate additional income outside of agriculture, this also restricting the potential for children to enter farming. The external income (i.e. through tourism) can become essential to the household budget and thereby lead to a further decrease in the time allocated to farming, where possible crops that are price supported will be sold through the co-operatives, and other crops at the local market. The need to maintain income levels in the face of limited alternatives for generating income outside of agriculture and the restriction of farming options that result from the prevailing natural conditions and degradation have placed considerable pressure upon this group.

3. The third group of farmers is identifiable in zones one and three and the western part of zone two. These have a greater diversity in their crops and the markets to which they sell. A high level of agricultural investment is made both through personal (family) commitment and expenditure on technology. This commitment is manifest through the supportive role played by the extended family and the tendency for children to enter farming on leaving high school.

(16) Price support is EU funded and guarantees a fixed price for produce that is sold through the co-operative marketing structures.

There is considerable flexibility among this group due to the level of commitment to farming and the use of « hidden labour » for marketing, work in the field, and the domestic consumption of some crops (vines, cereals etc.).

4. The final farming type cannot be geographically defined, although it does tend towards the central zones. This is based upon young farmers who are educated in agronomy and have returned from tertiary education with concerns about the biology of the soil and ground water and the need to reduce inputs and mix crops according to their specific natural characteristics and economic potential. They are often the offspring of elderly farmers who work the land according to a very different agronomic paradigm. The group also highlights one other important scale factor which refers to the transfer of knowledge, not only in terms of the technologies employed, but also through the adoption of information and insights that are acquired outside the area to that which is specific to locations within it.

This typology is based upon a taxonomic structure which is under further investigation with French mathematicians in an EU project on Environmental Perception. The research indicates significant variation in the propensity and willingness of different groups (elasticity) to adjust their farming practice in response to changing physical or economic phenomena. Further analysis of this issue is underway with the objective of identifying and linking viable policy packages to the decision or option spaces that exist in different physical locations, so that policy instruments are better tuned to the diverse recipients.

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Social enquiry and the policy relevant exploration of agricultural systems

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Abstract

The relationship between agriculture and the natural environment is determined by the physical characteristics of that environment and the decisions which affect how it is managed. However, as interdisciplinary method becomes more prevalent it is increasingly important to consider the means by which the relevant criteria to represent a decision issue, and the techniques to obtain information about them, are selected. This paper will propose that a range of social enquiry techniques can make a significant contribution to the policy relevant diagnosis of agri-environmental issues through the representation of those issues as they are perceived at the local level. It will also suggest that such techniques can supply data about changes in the natural system that is not readily available from more technical natural science procedures, albeit at a far lower level of definition. A case study into the processes of resource degradation in the Argolid region of the Peloponnese in Southern Greece has been used to exemplify this argument.

Introduction

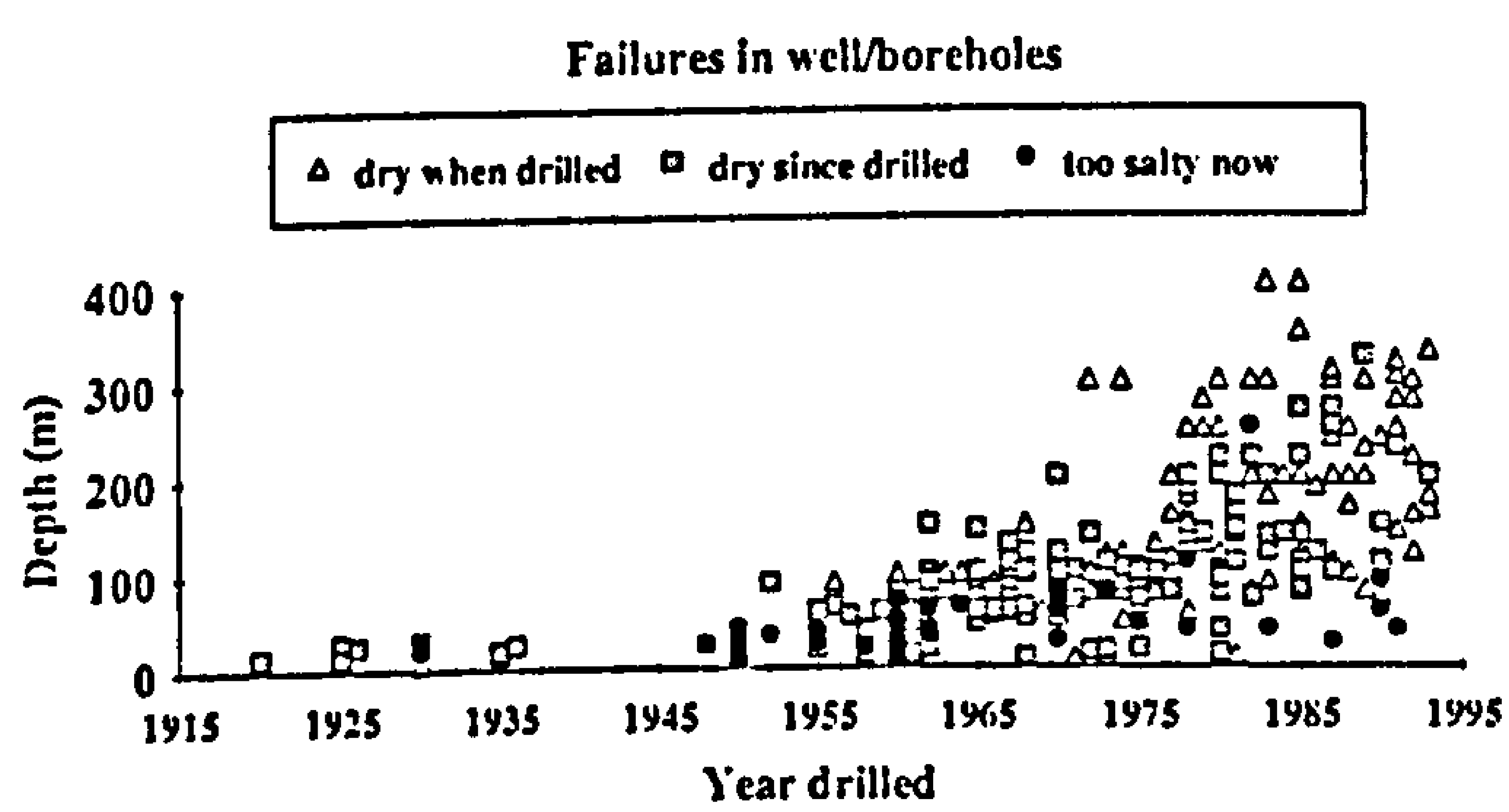
Transdisciplinary studies which relate to agriculture and the environment have emerged out of a growing acceptance that 'real world' issues are complex and do not conform to analysis or representation by single disciplines. Such issues need to be constructed as meta-problems which transcend existing disciplinary boundaries and as such are not easy to resolve through single disciplinary approaches or within institutional frameworks (Roome, 1993). Policy relevant research is essentially a diagnostic process which is oriented towards the structuring and systemic representation of an issue prior to the selection of the subject matter for more detailed investigation, and the theoretical and methodological tools necessary to pursue this. Single discipline studies inevitably use their own classes of phenomena as frames of reference for the determination of relevant information. These often exclude concepts such as scale, hierarchy and perspective which are a major issue in transdisciplinary investigation.

Some progress has already been made towards the integration of biophysical and socio-economic agricultural subsystems (Park and Seaton, 1995). This tends to have emerged from agricultural systems thinking and a recognition that the decision space within which farmers operate is not restricted to the physical characteristics of the land they manage. In contrast, criticism has been levelled at the social science community for devoting too much attention to paradigms, intellectual shifts and ideological studies (Molnar et al. 1992). Social enquiry, therefore, can contribute to agricultural science through a range of analytical and conceptual devices (i.e. from systems thinking and ethnography) and through the use of specific tools and techniques for data acquisition (i.e. elicitation techniques). This contribution can take a number of forms:

1. The elicitation of those attributes and processes that help to define an issue or system of interest and the investigation of how these are configured to determine the range of options that are perceived by a hierarchy of decision makers.

2. The establishment of a typology of decision makers (farmers in this example) which can inform about the range of responses to those options and the thresholds at which decisions are made.
3. The acquisition of data about the use of natural resources and the extent and nature of physical transformations.

The first two points form the basis for this paper, however, it is worthwhile recording that social enquiry techniques can be employed to acquire information about natural phenomena. This is often neglected by the natural sciences and undervalued by the social sciences (Lemon et al., 1994). Measurement within natural science is constrained by the available knowledge and technology and thereby finance. This in turn restricts the ability to represent spatial variation, and once a natural process has been identified as significant, to obtain historical data about it. Therefore a complementarity is evident between the acquisition of relatively few 'technical' measurements which cannot readily inform about how that transformation contributes to the wider picture and data of less resolution which informs about that wider canvas (Conway, 1985). While it is important to recognise that farmers respond to a situation as they see it they are also a valuable source of information about how and to what extent natural resources are used and the subsequent impacts of that activity on those resources. For example the accompanying figure conveys borehole failures through water depletion and salination and the increasing depth of drilling. This data was acquired from interviews with farmers which investigated the history of water use over two to three generations.



Background to agriculture and natural resource degradation in the Argolid[1]

The Argolid Plain is situated in the Peloponnese region of Greece, approximately 150 kilometres south-west of Athens. The area is dominated by irrigated agriculture which accounts for 89% of groundwater compared with 6% in total for domestic consumption and the balance being used for other industrial purposes. Over the past fifty years there has been a movement away from a more diverse rain fed farming system producing for local markets and domestic consumption towards the mono-cropping of irrigated fruit crops, in particular citrus (orange trees). The market for much of this produce is external to the area and is underpinned by a range of price supports and subsidies. This intensification of agriculture, with the accompanying increase in mechanisation and fertiliser and pesticide use is not sustainable and has led to the degradation of soil and water resources. This degradation has taken the form of water depletion with bore-holes in the area reaching 400 metres in depth and with increased uncertainty about finding water. There has also been progressive salinisation due to the intrusion of sea water as ground water levels have dropped and increasing problems with frost which reduces production levels and ultimately threatens the trees themselves.

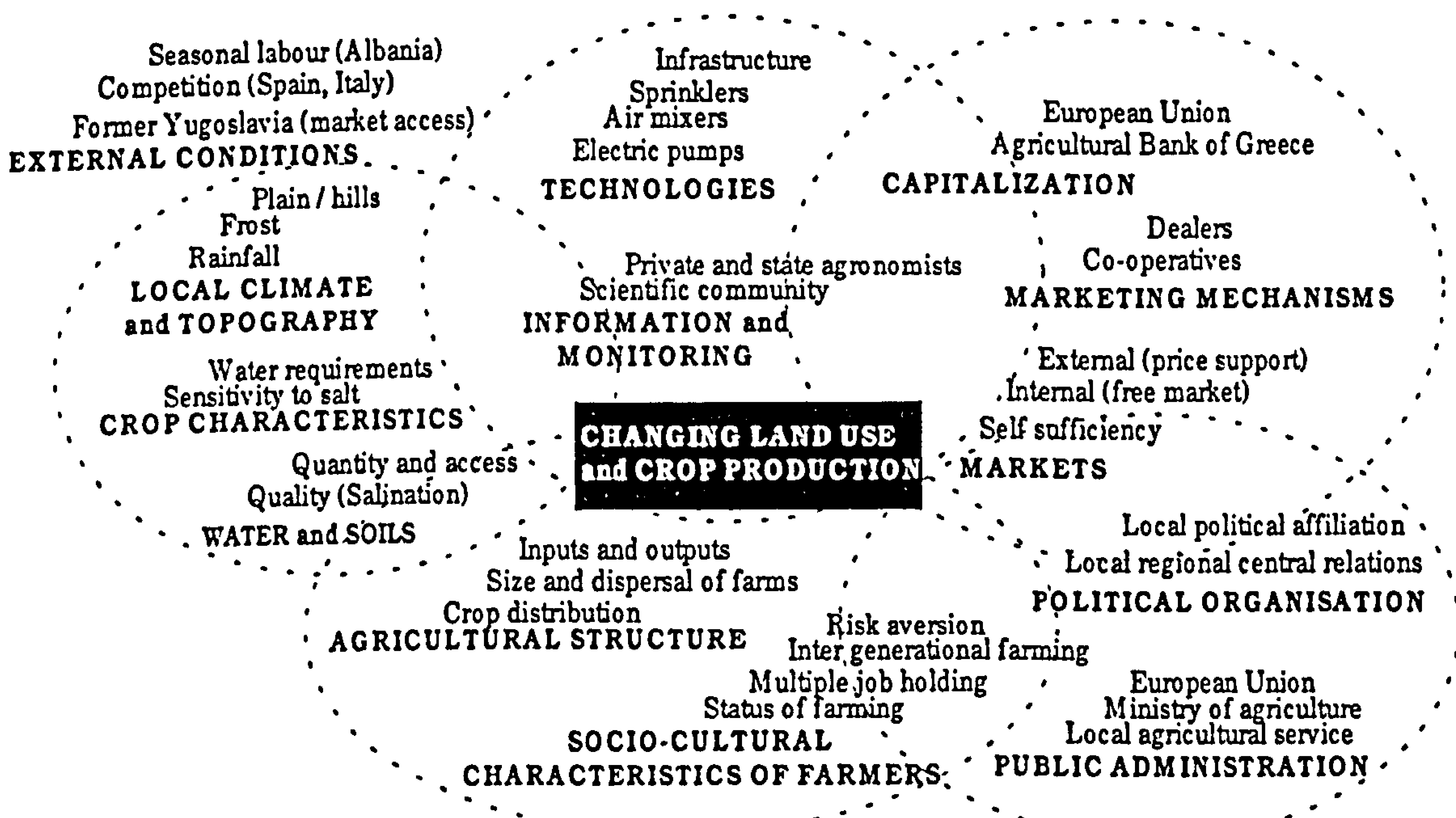
The response to this degradation, advocated by the scientific community and expressed through policies for remedial activity, has been to introduce further technologies (air mixers to protect against frost, deeper drilling capacity and infrastructure for water transportation) to perpetuate current production rather than to alter agricultural practice in an attempt to

[1]This work was funded by DGX11 of the European Commission as part of the Environment Desertification Programme, Archaeomedes (EV5V-0021) and Environmental Perception (EV5V-0486) projects.

reduce water use. In effect the area as a whole is caught in a technological spiral with relatively little understanding about the social and cultural criteria that may constrain, or support, the adoption of more sustainable forms of farm practice. In other words the success of any remedial programme is dependent upon an understanding of the receptivity (Seaton and Cordey Hayes, 1993) of farmers to different options. It is here that natural science and social enquiry need each other. Comprehending the physical characteristics of different crops (water requirements, vulnerability to pests and climate etc.) must be related to the social criteria that affect its viability as a cropping option (commitment in time and capital and knowledge requirements etc.) and vice versa.

Diagnosing a policy relevant issue and the relevant system of interest.

The process of resource degradation in the Argolid highlights the inseparability of social and natural phenomena and the need for a conceptual framework for framing issues and specifying the information requirements related to them. The need for such a frame assumes that there is seldom a consensus about what constitutes an issue, its magnitude, its evolution and what remedial options exist. For example there was not a homogeneous perception about the issue of degradation in the Argolid. The farmers refer to the 'problem' of water when, in quality and quantity, it becomes more difficult to obtain for irrigation. On the other hand hydrologists may refer to a 'problem' which relates the demand for water to the depth, and salt content, of the aquifers. A soil specialist, however, may perceive a 'problem' when the soil deteriorates in its ability to support vegetation and an agronomist with the loss of ability to grow a particular crop.



A broad systemic map representing the perceived processes, agencies and interactions relating to an issue (agricultural production and degradation) can be obtained from semi-structured interviews with key actors (i.e. those involved in agricultural production in the area, farmers, agronomists, drillers, scientists). While the initial focus should be on the issues of concern the processes to which linkages are perceived need not be restricted either by issue, time or location. For example the perceived relationship between crop choice (farm level), the provision of information from the Service of Agriculture (regional) and price guarantees from the European Union. The above figure conveys the range of processes and agencies that were seen to constitute the system of interest around the issue of agricultural production and degradation. Related to these processes are a number of additional questions about how they can be represented, what information is appropriate for that representation and what disciplinary techniques should be adopted for obtaining that information?

The accompanying table shows how this system of interest translates into the socio-economic and physical dimensions that determine farming decisions. These represent the basic attributes which, under various configurations, determine the options that are open to farmers across the region. The term dimension was chosen specifically to represent a range within each attribute (i.e. from high status attached to farming to the work being held in low social esteem) as well as the possible combinations between them.

Table 1. Dimensions of farming option space in the Argolid Valley.

Socio-economic dimensions	*Physical dimensions*
Reliance upon seasonal labour Capital/labour investment Labour : Technology ratio on farm Social acceptability of farming Adoption of local, external markets Level of self-sufficiency Variety of crops grown	Soil quality Topography Micro climate Availability of water Quality of water Productive level of crops Crop vulnerability
Economic organisation	*Information-public administration*
Price support and subsidies Marketing efficiency (co-operatives, local market activity) Water and technology prices	Level of infrastructure Effectiveness of agricultural extension service Patronage-political involvement

Typology of decision makers

Combinations of these socio-economic and physical dimensions have been used as the basis for a broad typology of farmers. This provides an insight into the range of possible responses to policy options (i.e. price support and subsidy of crops, water pricing and rationing, technological and managerial support). It is important to note that, for reasons of space, this typology has been presented without reference to its spatial distribution. If such groupings were scattered evenly across the landscape then such a typology would be of far less interest. However, because a spatial structure is apparent (see Allen et.al. 1994) the implications for policy exploration, at a local level, are far greater.

The first group are predominantly monocroppers of irrigated citrus trees with high productivity per unit and the adoption of the European Union price support system rather than local markets. A high level of technology is employed to offset the effects of degradation. Primary employment and investment are outside of agriculture and the ability to farm in a more diverse way is constrained by limited family and personal commitment to working the land. The low status accredited to farming within this group is further exemplified by the tendency for farm children to enter higher education and move into occupations other than farming. Due to the existence of second incomes the farming behaviour of this group changes little with changes in orange prices. They are thereby able to withstand price reductions and as such are less vulnerable, in economic terms, to degrading natural resources. They are however less flexible with regard to labour intensive cropping options.

The second group have larger farms with limited crop variety and low levels of technological investment to combat the effects of degradation. There is low productivity due to water degradation and poor soil in the areas that they farm. These farmers are therefore constrained by the need to generate additional income outside of agriculture, a factor which also restricts the potential for children to enter farming. The external income (i.e. through tourism) can become essential to the household budget and thereby lead to a further decrease in the time allocated to farming. These factors have restricted the ability of this group to adopt cropping options which require high levels of labour or reliable, good quality natural resources.

The third group have a greater diversity in their crops and the markets to which they sell. A high level of agricultural investment is made both through personal (family) commitment and expenditure on technology. This commitment is manifest through the supportive role played by the extended family and the tendency for children to enter farming on leaving high school. There is considerable flexibility in the type of farming undertaken by this group due to the level of commitment to farming, the use of 'hidden labour' for marketing and work in the field and the domestic consumption of some crops (vines, cereals etc.).

Conclusions

It has been argued that natural science has begun to recognise that change cannot be effected within farming systems simply through an improved understanding of the characteristics of physical phenomena. Equivalent insights into the basis for decision making by farmers are also necessary. Social science has been slow to take up this mantle, preferring to concentrate on theoretical issues rather than interaction with agricultural science and farming communities. It is only through this interaction that a systemic picture can be elicited which represents the attributes and processes of production and degradation and thereby the range of options that are realistically open to local decision makers and on which viable policy can be formulated. In addition, more structured enquiry techniques can also provide data about changes in physical systems that can provide an overview which is not available to natural science.

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THE ARGOLID CASE STUDY
A Sub-Project of ARCHAEOMEDES

An Integrated Physical and Socio-Economic Computer Model of the Argolid

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SUSTAINABLE WATER USE IN THE ARGOLID:
A SUB-PROJECT OF ARCHAEOMEDES.

Funded by DGXII under the Environment Programme.

By P.M.Allen, M.Lemon, R.Seaton at IERC Cranfield, in association with
the Agricultural University of Athens.

1. Introduction

As part of the ARCHAEOMEDES project 1993-95, a study was carried out concerning the situation in the Argolid plain in Southern Greece. The team led by Professor Poulovassilis at the Agricultural University of Athens, specializing in hydrology, had for a number of years been involved in the problem of supplying water to the increasingly intensive agriculture of the region. As part of the "Desertification in the Mediterranean Region" programme he had drawn attention to the fact that the problems of the Argolid were not particularly driven by "Climate Change", but instead by the action of farmers turning increasingly to irrigated agriculture. This had led to the lowering of the hydraulic head in the aquifers, the penetration of sea water, and the transfer of salt to the land, reducing future yields.

The area of irrigated crops grown in the Argolid has increased from about 4,600ha in 1945 to around 19,500ha in 1990, with prospects of this continuing to grow. As a result, the amount of water drawn from the aquifer has grown from some $45Mm^3$ to about $145Mm^3$ today. Because this exceeds the natural recharge rate of the aquifer from rainfall, then the level has fallen, sea water has invaded the aquifer, and as a result irrigation has lead to a continuing salination of the soils, and to falling crop yields.

Faced with these problems, various actions have been undertaken. Over 30 years ago a first canal was built to bring spring water to the coastal fringe where salt was already a problem. However, the growth of irrigated crops has led to a much larger problem, and a new, much larger canal has now been built to bring the water from the Kiveri springs to the plain to allow the continued production of citrus fruits. This may lead to further problems, since the water of the Kiveri spring has become rather salty in recent years, and therefore, if used for irrigation will result in the addition of some 93,000 tons of salt per year to the soil.

This path of economic development also gives rise to considerable problems with regard to equity, in the distribution of this water to central and peripheral farmers of different kinds. The original problem of salinity of the aquifers and the soils, and the reduction in volume of the aquifer to about one half its natural volume, has been caused by the farmers in the central and lower parts of the catchment developing excessive areas of irrigated citrus fruit trees, and also by using very wasteful "flood irrigation" methods. The original canals had served mainly these farmers, although by 1990 the farmers at the periphery and at the back of the plain were having to bore wells down to 500metres, and then were often finding only salty water. With the construction of the new Kiveri canal the problem of its route, and of the distribution of the new water resources provoked much controversy. How can such questions be viewed in an integrated manner so that the overall advantages and disadvantages can be weighed? Although the policy decision has been made in the Argolid, there are many other places where similar questions are arising, and a means is required to examine the overall issues involved in using such vast technological means to continue the expansion of irrigated farming. Who gets what long term benefits and who pays the costs of such a scheme? What "side-effects" might emerge? How long will the system function as proposed? Since it is the decisions of farmers, influenced by price supports and subsidies as well as changing costs, that has driven the system to the present situation, then what policies or actions will influence them in such a way as to follow a more "sustainable" path than they have until now?

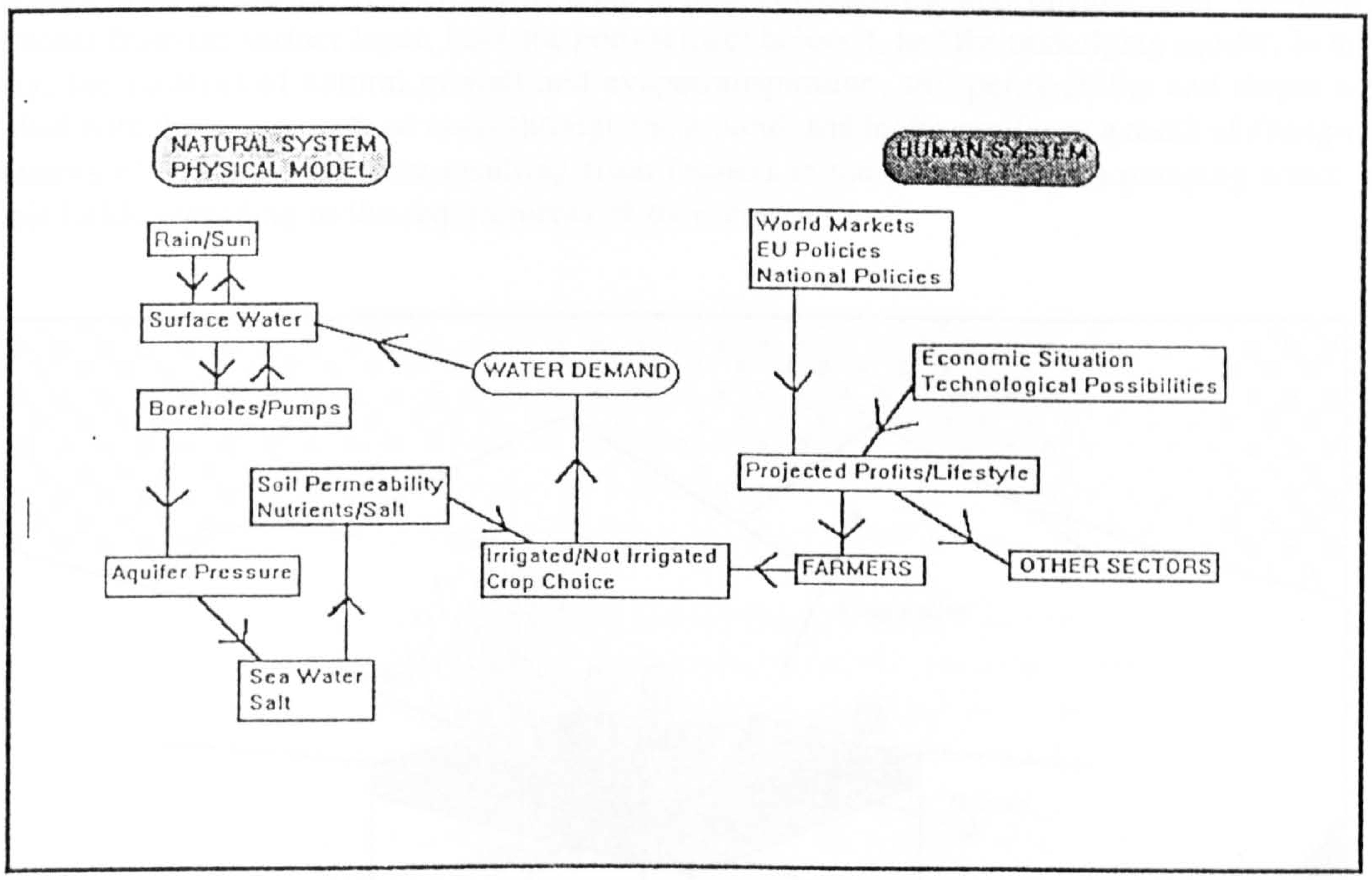

Figure (1). The structure behind the integrated model developed for the Argolid.

What is needed is an integrated vision of both physical and agricultural realities, as well as the economic and technological factors affecting farmers decision making, and the beliefs, agendas and goals that they bring to bear on these. In response in the "ARGOLID" project we are developing an integrated, hydrological, agricultural and socio-economic model as a basis for such policy exploration and decision support, and a generic methodology and tool for dealing with the many similar problems that exist elsewhere.

2. The Physical Model

The long term process underlying the "Argolid" problem is that of Urbanization. The on-going process of urbanization is running fast in the Mediterranean, and the coastal areas are all the scene of increasing urban populations, and of the intensification of agriculture. In an attempt to obtain rates of return on capital that are comparable with those of "urban" activities, traditional farming practices are being replaced by more "modern" ones, with more lucrative crops, requiring increased use of water resources through irrigation. In the case of the Argolid, the lure of greater profits from irrigated agriculture has led to the steady increase of irrigated land, from the 4.5kha in 1945 to some 19.5kha today. The overall result of the decisions of many farmers across the Argolid has led to the gradual increase of water demand form some 45million cubic meters to 145million cubic meters, which is far above the natural replenishment rate of the aquifer, and so has led to bothe shrinkage of the aquifer to half its "natural" volume of 2billion cubic meters, and has also led to the incursion of seawater inot the aquifer, and to the transport of salt to the irrigated land.

The physical model describes in detail the movement of water through the system on a rather fast time-scale, filling out the detail of the left hand side of figure (1). The model takes daily steps forward in time, and taking each spatial zone in turn, considers the net "in-flow" and "out-flow" of water from the surface layer, from the porous layer below it, and the underlying aquifer. In this way, the patterns of natural rainfall and evapotranspiration, soil permeability and slopes are linked with the movements of water through the ground, and in the aquifer as a result of changing patterns of hydraulic pressure resulting from farmers in the different zones pumping water to their fields according to the requirements of their crops.

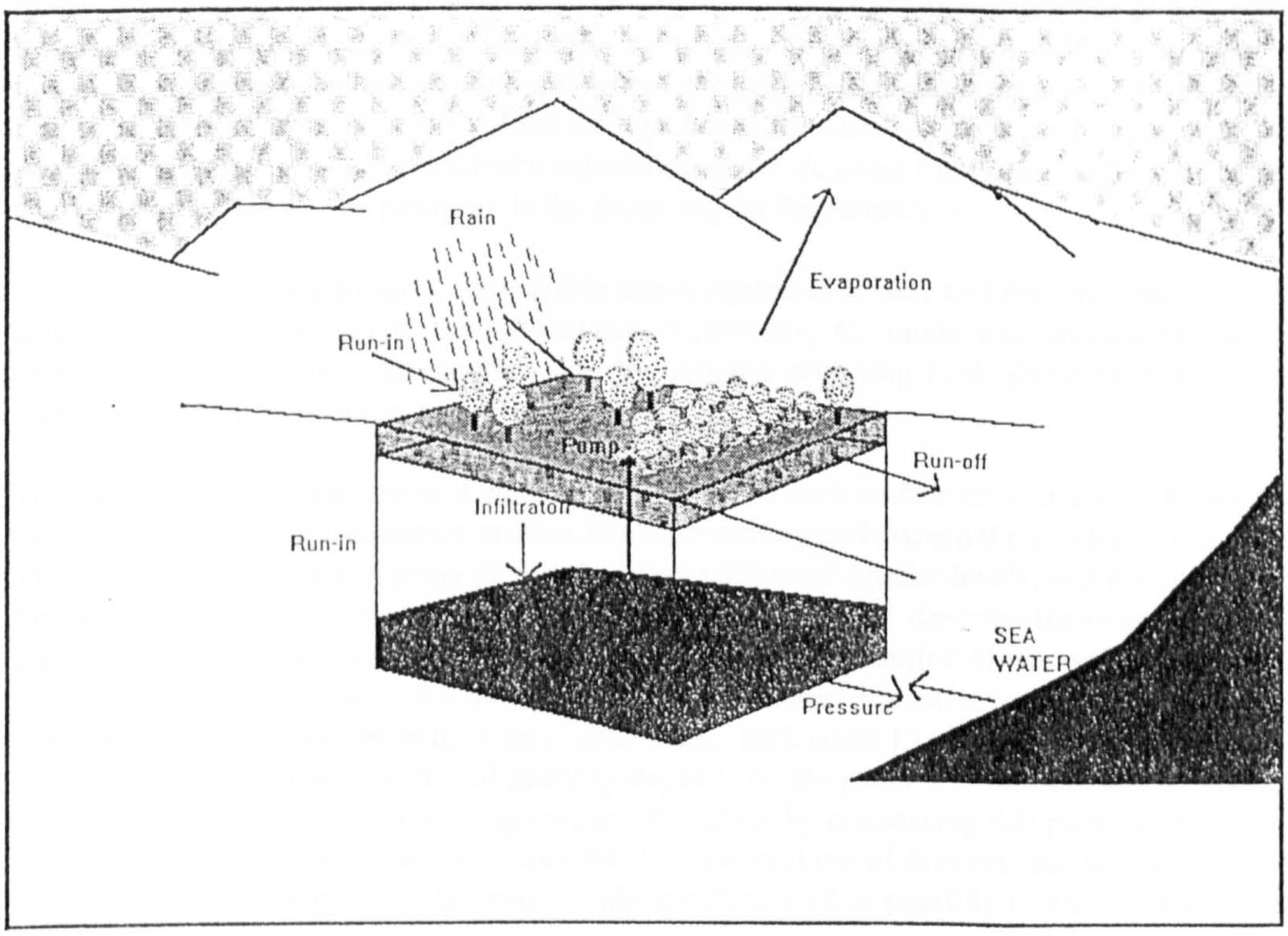

Figure (2). The physical model of the Argolid describes the flow of water to and from the surface layer and in and out of the aquifer. Salt from sea water is moved with the water.

This rapid, physical dynamics of water movement, occurs within the much slower process of annual crop choice that farmers make on an annual basis. So, the computer simulation considers the crop choices in each zone made each year, and then imposes the resulting demand for water in the surface zone onto the physical model.

The detailed data for rainfall has been used to generate the pattern as observed from 1962 until 1992, and then, using this as a basis for a probability distribution, this is used to create "future" rainfall for simulations exploring into the future, which have the same patterns, but of course, which can be adjusted to examine the effects of possible "climate change", for example reduced or increased rainfall, on the behaviour of the system. The preliminary model developed was used 7 spatial zones to represent the integrated behaviour of farmers and the physical system, although a much more detailed hydrological model has also been built, using zones of 500m squares and this model will be used in the future to represent the hydrological flows more accurately.

At each time step, for each zone the amount of surface water present is examined. For the hectares of Olives and Cereals, the surface water is not critical, and so these are simply considered to grow normally. However, for the hectares that have been planted with irrigated crops such as citrus or vegetables, if there is sufficient water for the crop, then no action is taken and the crop grows normally, but the surface water is insufficient because it has not rained, then the farmers in the zone will pump water up from the aquifer to irrigate their fields, or will use water from the canal system if it is available.

In this way the farmers irrigate their crops mostly in summer, and hence extraction of water from the aquifer is greatest at this time. However, the farmers also use a considerable amount of water in winter, when they use pumped ground water to increase air temperature when frost threatens. This usage can account for 25% of the use by certain farmers, and so it is of importance. The computer simulation uses a probability calculation to decide when frost risk is highest during the year, and switches on the pumping in the same way as the farmers do.

In this way, for any pattern of irrigated to non-irrigated land-use, and for any particular crop choice, then depending on the rainfall that occurs each day, the model can simulate the amount of water extracted from the aquifer, and the amount returning back down to it by natural recharge, and by infiltration back from the plain.

The model considers the flows of water in and out of the each surface zone, and then for each of the layers below these, and then considers the water exchanges between the aquifer of each zone. This enables the model to generate the changing pattern of aquifer levels, and the consequent flows of water between them. This in turn enables the system to describe the incursion of sea-water into the aquifer, initially along the coastal edge of the aquifer. However, because of the negative hydraulic pressures that aquifer extraction generates, this salt is transferred, with ground water, back into the aquifer behind the coastal zones, back some 15 kilometres to the back of the Argolid plain. The precise path and quantity depends on the patterns of rainfall and of irrigated crops that farmers have decided to grow, and therefore, by connecting this physical model to a "human" system model which captures the decision making of farmers, the whole integrated model can be used to generate alternative "histories", as well as possible futures for the system.

3. Agricultural Decision Making

Having described briefly the physical modelling, we now turn to the part that is vital for any consideration of future actions, or policy. It is as a result of farmers' decisions that the aquifer has been severely reduced in size, and that salt has been drawn in, and has reduced the productivity of much of the region. If we want to investigate any possible remedial actions, policies or schemes, then it is important to know why farmers make the decisions they do, and how they might respond to opportunities or threats in the future. Instead of simply using data on the area of irrigated land to "drive" our model, in the Argolid Project a great deal of time was spent interviewing farmers, in order to elicit from them the factors that influence them, the costs and benefits that they consider, the risks that they run, and their responses to those risks, and, importantly, the rates at which they can respond to changing opportunities, and the thresholds they perceived in those decisions.

In reality, it is the decisions of these farmers that has led to the over-exploitation of the aquifer in the Argolid, and so if we are to engage in some remedial action or policy it is vital to know what the response of the farmers will be, and how it may affect their behaviour. For example, we might want to know how farmers would respond an increase in the supply of fresh water. If they would simply increase their production until exactly the same situation was reached again, then this would be important. If, on the other hand, the increased supply of fresh water was accompanied by the imposition of some heavy water taxes, then we need to know if this would simply lead to farmers abandoning farming, and migrating to Athens.

From the many interviews conducted by our team in the region, it was possible to extract very clear information about the increasing failure of wells across the region, and to get a very good picture of the spatial pattern of salination and of water resource problems. Information was also gathered concerning the costs involved in farming the different crops, and in moving from non-irrigated to irrigated crops. This allowed us to calculate the profits that particular farmers in a zone could expect from a hectare of each of their possible choices, given the labour involved, the water or costs of drilling, for seeds, fertilizer, for electricity, and for transport. The calculation took into account the type of soil, and of course, the changing yield that could be expected depending on the growing level of salination experienced. All these factors led to the calculation of the parameters which successfully generate the different hectarage of crops observed in each of the 7 zones in 1992.

In addition to this, however, the delays that farmers experience in changing crops were also estimated, so that if the hectares actually observed in a given year for each crop would not necessarily correspond to the hectares "desired" by farmers for maximum profit, an economic equilibrium, but instead to a disequilibrium state about 10% closer to this. Each year, however, because the "expectations" of farmers may change either with changing prices for crops or as a result of changing water costs, water quality or of falling yields, the desired hectarages to which they are moving change, and so the pattern of crop choice reflects the decisions of farmers moving "towards" a target that is also moving. In other words, part of the dynamics of our system, results from the time delays involved in the decisions of farmers about land-use. economic

4. The Integrated Model

The Argolid model that has been developed results from the combination of the physical model with the human decision making model outlined above. This allows us to run different possible histories of the Argolid, depending on the policies and decisions made in earlier years. We can therefore start our model from the conditions of 1960, and run it forwards until today, to make sure that we understand the present situation, and verify that our model successfully regenerates the present as at least one of the "histories" that could have happened.

The model considers 7 spatial zones and 3 layers: the surface, the subsurface layer that may be permeable or not, and the aquifer. The figures below show the computer screen as the model runs. For each zone there is a circle whose size represents the total hectarage of the zone, and the different segments correspond to the relative number of hectares of each type of crop in that zone for that year. The state of the aquifer under each zone is shown by the indicator of how full or empty the aquifer is. The times and amounts that farmers pump ground water is indicated by the flashing column for each zone, and the hydraulic heads, surface salt concentrations, profit per hectare, salt in particles/per million in the aquifers are all shown on the left of the screen. In the upper right hand corner a Garah of the annual rainfall is shown, and in the lower right corner, the total economic yield of agriculture in the Argolid is calculated, with the total water demand for crops, and the total size of the aquifer.

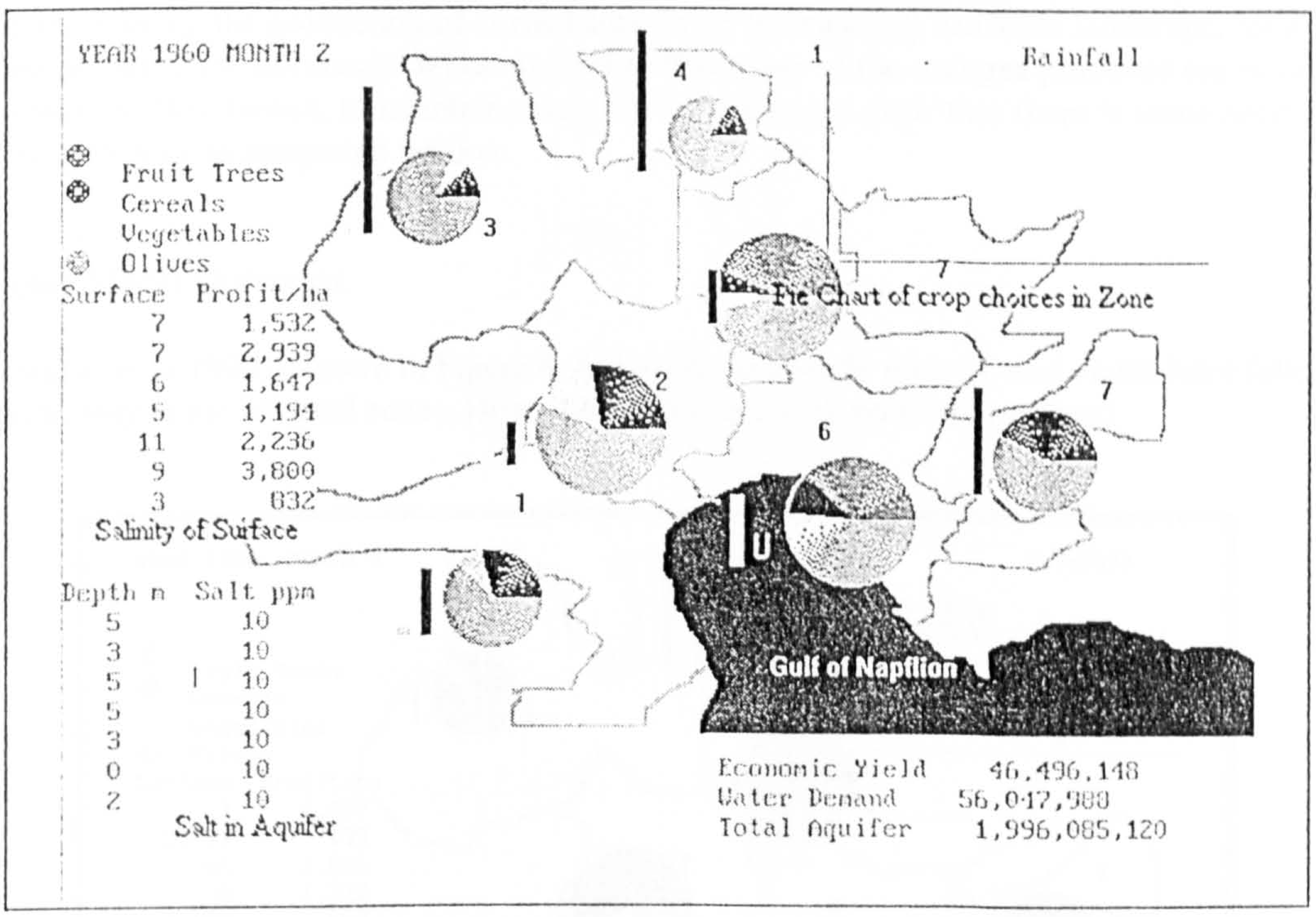

Figure (3). The screen display for a simulation which is 2 months into a run starting in 1960. Profits are high in the different zones, and citrus growing is mainly in zones 5 & 6.

Initially, before large scale irrigation occurred, there was a gentle, positive hydraulic head throughout the system, which meant that the aquifers were pure, and that there were some marshy areas of land. There was a steady transfer of the catchment water to the sea. However, as the hectares of irrigated land were increased, the overall water balance of the ground water changed, and at around 1960, it became negative. The coastal zone irrigation rapidly led to the incursion of sea water into the ground water, with a consequent transfer of salt. The continued irrigation pumping transferred the salty water from the aquifer onto the surface, where, gradually the productivity of the soil was eroded.

In response to this, a first, small canal was built which brought spring water from the western corner of the Argolid, and this water was used for irrigation along the coastal strip. While this allowed intensive fruit tree growing to continue, the farmers further back from the coast continued to expand the area of irrigated crops and hence the amount of water pumped from the aquifer.

The lowered hydraulic pressures led water to feed back from the coastal aquifers, thus transporting sea salt underground some 20 kms inland. Gradually then, the salt problem has increased as a result, so that a large canal project was put in place to deliver spring water over a wide area of the plain. In addition, the lowered water level of the aquifer has meant that farmers in the periphery have found it increasingly difficult to get water at all, and so there is a demand for water to be delivered from the large canal both because of salinisation, and because of water demand. The problem is that fresh water is something with a limited supply, and the sources used have also been growing more salty, and so ever greater technological interventions may be called upon to maintain the production of citrus fruits, in an increasingly artificial landscape, totally reliant on costly infrastructure. When we realize that many of the oranges produced are in fact not consumed but buried, to maintain market prices, it seems clear that there is some need to review policy in an integrated fashion.

5. Some Model Outcomes

The situation in 1990 is shown in Figure 4. Salination is already serious, and yields have fallen considerably in the affected zones. How will this evolve with no further action?

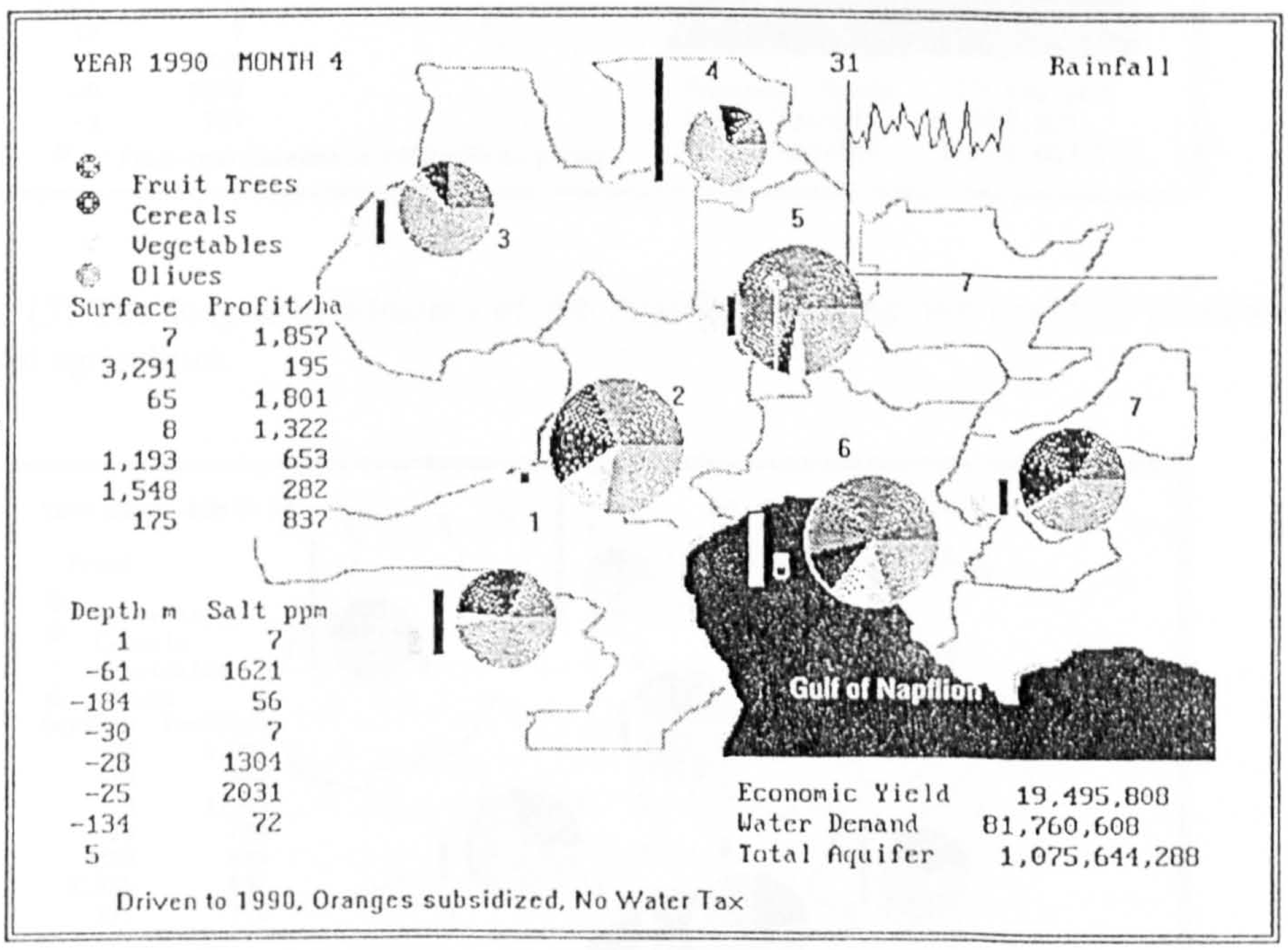

Figure (4) The situation in 1990. The aquifer has been halved, salt concentrations in Zones 6, 5 and 2 are extremely high.

If we run the simulation on, then we arrive at the situation of figure (5) by 2020. The production of citrus fruits collapses, leaving soils with extremely high salt concentrations, reducing yields of the replacement crops that are tried. Generally, the systems returns to Olive growing, but at considerably reduced yields, so that the agricultural revenue of the region falls to 17billion drachma, and will never recover.

The integrated model can be used to explore the effects of different possible policies, which may involve taxes on water supply for agriculture, or subsidies or price support of various kinds. The simulation of figure (6) shows the effects of a water tax of 150drs/m3.

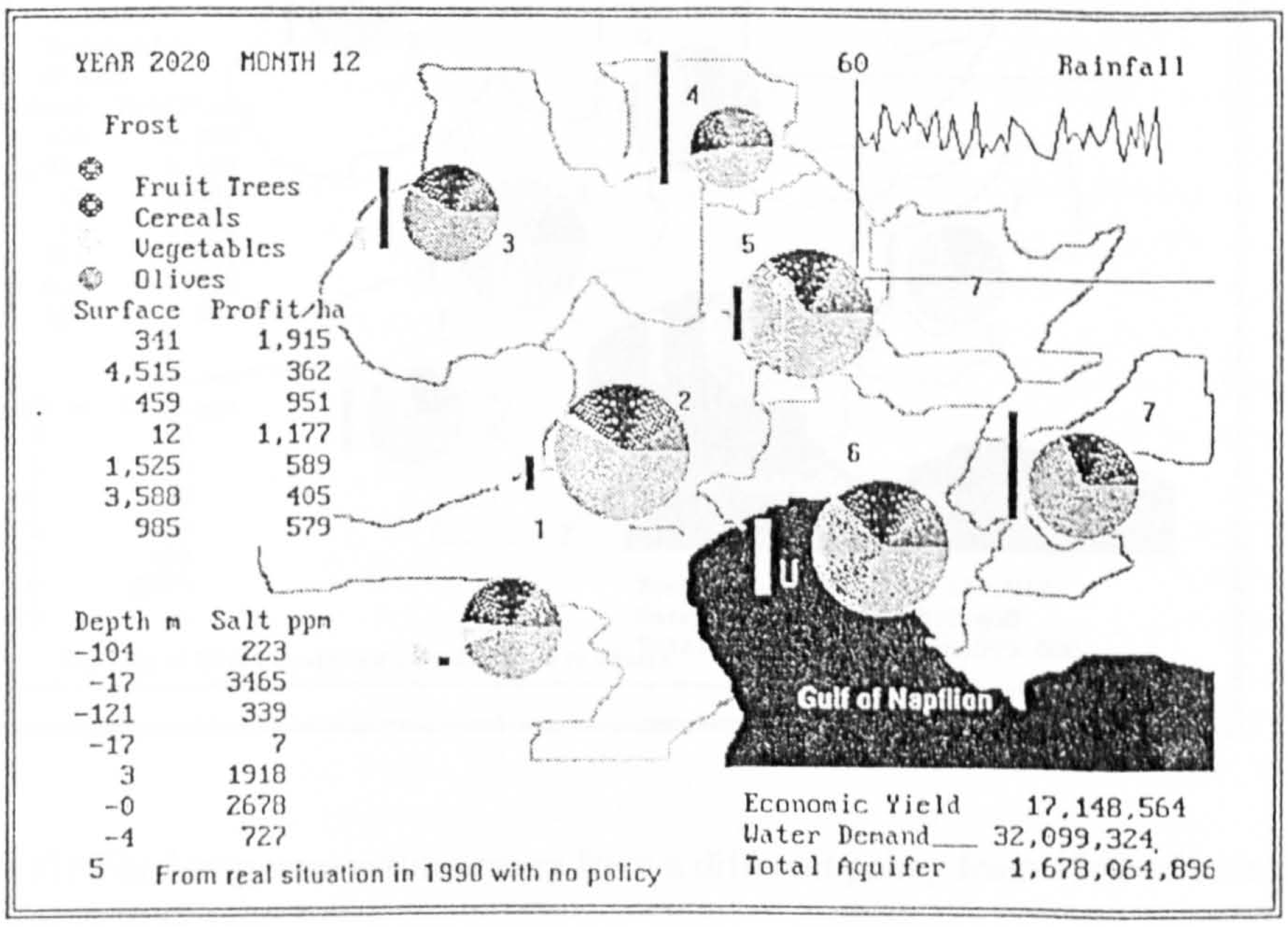

Figure (5) The long term situation of the Argolid following the eventual abandonment of irrigated agriculture.

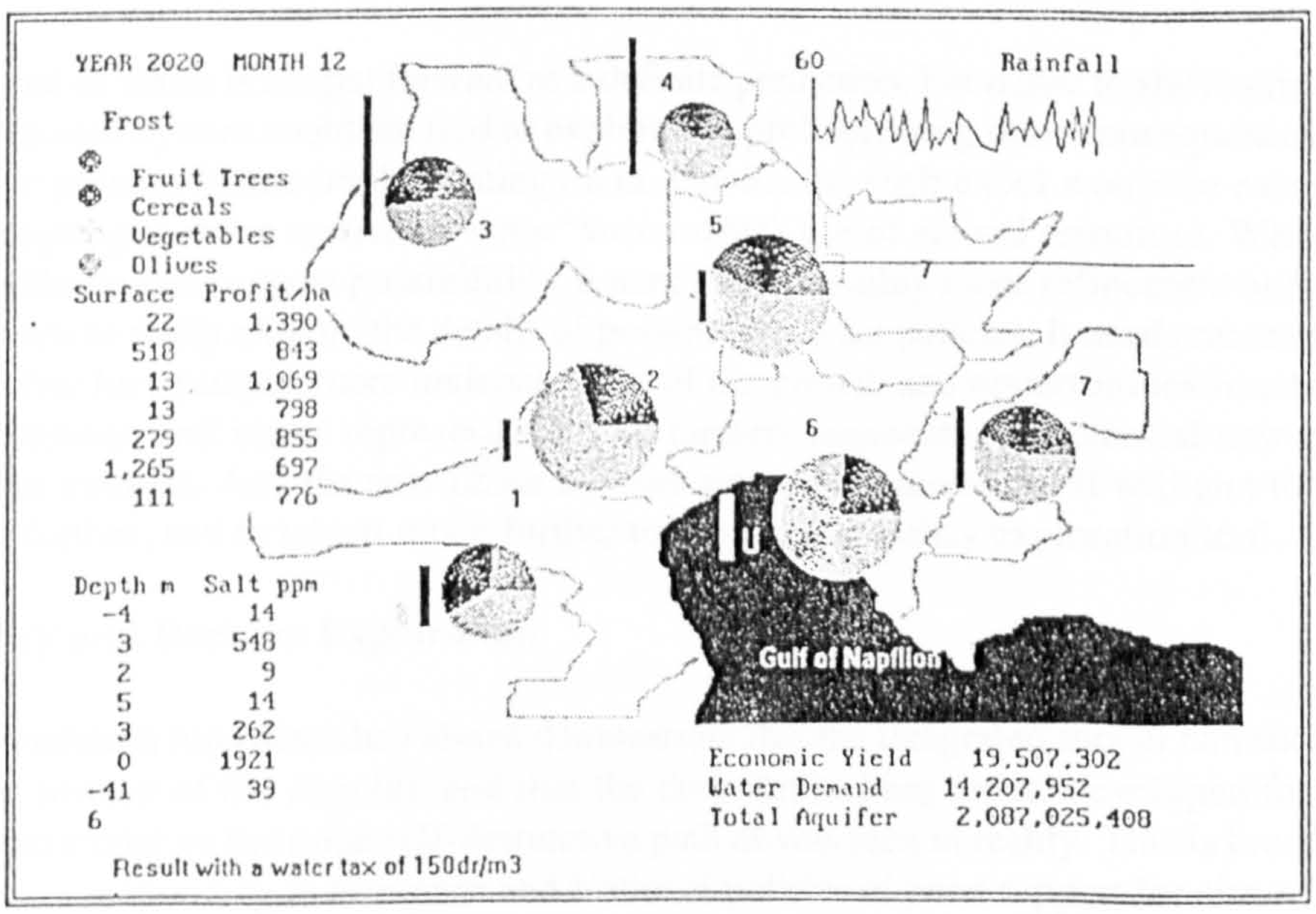

Figure (6) The long term result of a water tax of 150dr/m3. Not a large change.

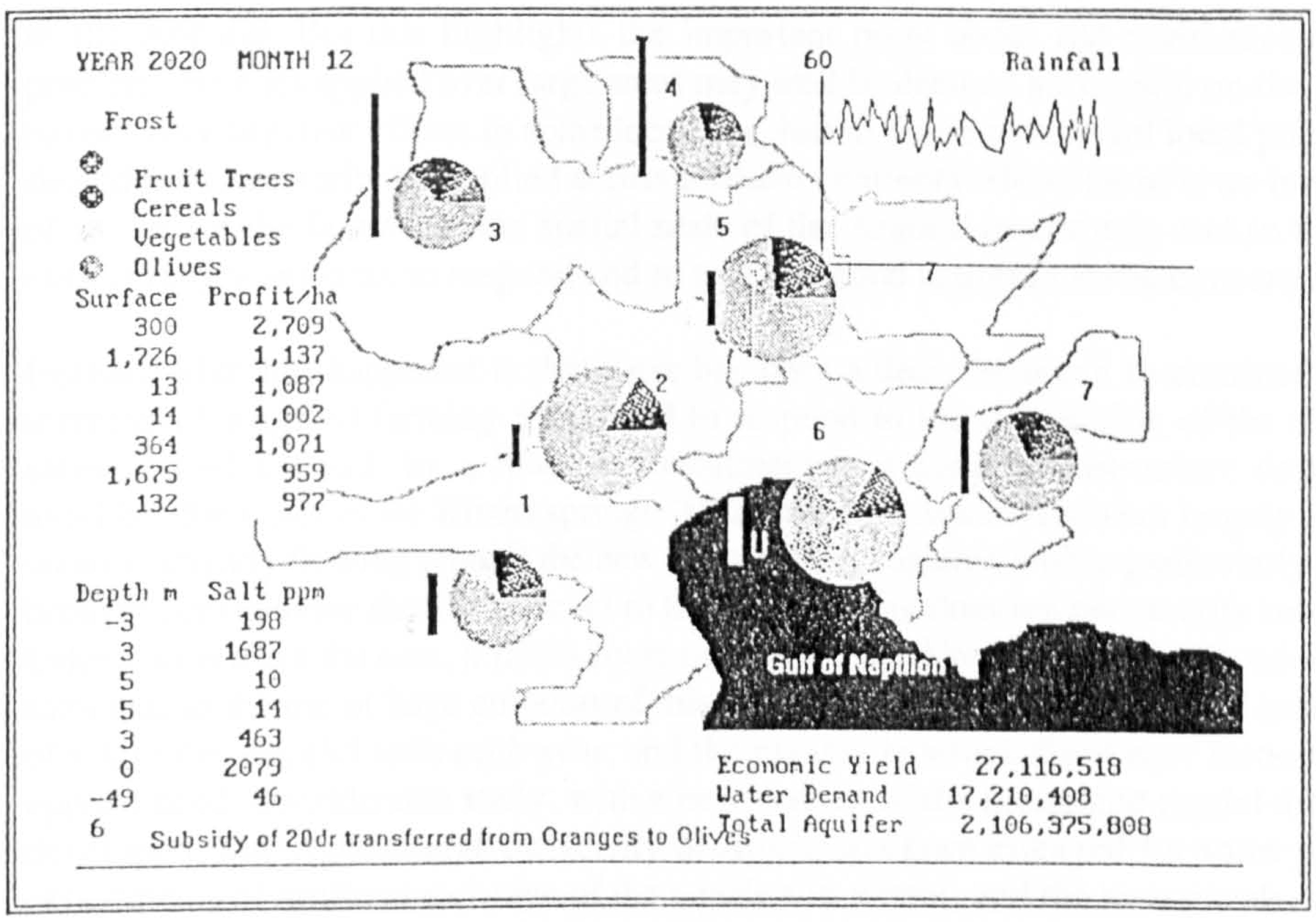

Figure (7) The Long term result arising from a different policy from 1960 of switching 20drm from Citrus to olives.

In figure (7) we see that the model suggests that if citrus production had not been encouraged by price support right from 1960, but instead there had been a subsidy on olives, then this would have led to a long term agricultural production worth 27billion drachmas. This would be sustainable for all time.

This kind of result is not put forward as a definite prediction, but rather to show simply how such an integrated system could be used to explore the probable long term consequences of different possible policies before implementing them. Obviously, such a tool would be extremely useful in attempting to move towards a more "sustainable" use of natural resources. While the simple model above can suggest possibilities, it needs considerably more refinement and depth if it is to be used to really explore the details of possible remedial policies. It needs more realistic price elasticities for example, more understanding of the growth and opportunities in other sectors of the economy, and better representations of farmers responses, of potential new crops and of possible markets. And the new phase of work under Archaeomedes II will aim to improve the model further, and to take it much further towards a real policy exploration tool.

6. Policy and Decision Exploration.

The simulation runs described above demonstrate that the integrated model can successfully re-run the history of the Argolid, and that the decision making model developed for the farmers leads the model on the same self-destructive path as was seen in reality. This is broadly the result of farmers responding to European and National policies of price support for citrus fruits, which made them very attractive, and led to the steady increase of irrigated farming. These policies were of course applied to much larger areas than just the Argolid, and it is quite possible that their effects, at that larger scale, were quite different on average than the destruction that resulted in the Argolid. But this highlights the important point about the multi-scalar nature of the problem. Policies applied over large areas may well be deemed successful on the average, while having very negative effects in some localities, just as some successful local policies or actions should not necessarily be applied across a whole continent. Here, there is no institutional level of action for the farmers at the spatial scale of the Argolid catchment, and so they are unable, even if they wanted to, to respond and to take remedial action in some concerted way.

Instead, what has happened is that there has been a decision taken to continue to support the increase of irrigated farming areas, and to respond to the diminution of the aquifer, and the salination of the soil, by a massive investment in a canal infrastructure designed to make available the water of the Kiveri springs. This large investment has been largely completed, and water is already flowing around the new canals. This, together with a particularly wet winter has brought considerable short term relief to the situation, but does not necessarily solve the problem. Indeed, as is often the case, it raises some new problems. The water of the Kiveri Springs is fairly salty and so the use of large amounts of this water may lead to the addition of around 93,000tons of salt to the Argolid soils each year, and the manner in which these new resources can best be applied needs considerable study, with a new version of the integrated model that is now being developed. The Agricultural University of Athens has been engaged for some years already in experiments of artificial recharge of the aquifers in winter, and the new canals offer far greater opportunities for this. However, the precise manner and pattern of recharge that is adopted has a very strong effect on the growth or decline of salinity at different locations and so this is also an important potential use of the integrated model.

Another factor that will need to be investigated is what the farmers response to greater water availability will be, and whether in fact increased supply will simply lead, with a delay, to increased demand, and to a return to the same problems as before. Policies concerned with "demand management"can also be investigated using our model, and this seems important if the remedial actions are to succeed.

Of course, other issues such as climate change are also important in the long term, and the integrated model allows us to explore what the combined physical and socio-economic response, might be if rainfall declines and temperatures rise as is forecast.

What is also important is that this situation in the Argolid is being repeated in many other locations, and is in reality, part of the unsustainable hidden reality of urbanization. As populations have shifted to the cities, so the decision makers are increasingly divorced from the reality of the natural system that really supports the cities. Cities not only "self-organize" themselves, but also their own and distant landscapes. The dubious power of economic exchange ensures that cities continue to maintain their supplies, if necessary with more intensive exploitation at greater distances, essentially "strip-mining" the world's agricultural land.

There is clearly a need for an integrated framework which will allow an appreciation of the net change in real "wealth", meaning not just the temporary flows of money captured in GNP, but the value of biological potential, the stocks of fertile soil, fresh water and other natural resources, which support the urban as well as the rural population.

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CONSUMER PERCEPTIONS AND LOCAL GOVERNMENT: THE ENGLISH DIMENSION

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(So far as Peter Hart is concerned the views expressed in this paper are his and not necessarily those of 'The Commission for Local Administration in England')

CONSUMER PERCEPTIONS AND LOCAL GOVERNMENT: THE ENGLISH DIMENSION

"Vox populi suprema lex" Marsiglio of Padua

Introduction

This paper argues that there is a mis-match between how individuals in communities on the one hand and central and local government on the other perceive environmental change. It will be argued that this mis-match stems from the provision of inadequate information about consumer need as the basis for decision making. This is due partly to the adoption of inadequate techniques for measuring consumer satisfaction. More significantly this measurement is invariably in response to the quality of existing services rather than identifying what actually constitutes consumer need.

Although this paper draws on examples from the Commission for Local Administration in England, and the land use planning system, the basic thesis holds good for all areas of local government activity which involve forward planning. The theme is that properly analysed feedback from the consumer, will, when incorporated in the decision-making process, produce better and more appropriate decisions about environmental change. (This may, incidentally, depoliticize some decision making) This, it is submitted, will produce a more integrated and local system of decision-making and service provision that is capable of adapting to the unintended consequences of planned change. Need cannot, therefore, be assessed and managed through the allocation and adherence of each sector of local government to separate and distinct responsibilities. Change and need does not conform to these sectoral distinctions and cannot be managed as if it does. More importantly, it will be argued that the agenda for local change should be set by, and respond to, the variation in consumer demand and not according to the conditions imposed by service supply.

There is a variety of evidence concerning public dissatisfaction with the land-use planning system. For example:

- After public local enquiries into major planning applications local people affected by a decision to grant that planning permission have expressed dissatisfaction with the fact that there is no right of appeal for local people who will be affected while the developer has had a right of appeal to the Secretary of State.

- The reports of the Local Government Ombudsman into complaints by individuals reveal a widespread discontent on the part of those whose amenity has been affected by grant of planning permission and who feel that their views have either not been sought by the local planning authority or, if they have, those views have not been taken into account. The Ombudsmen receive more complaints about planning than any other area of local government activity apart from housing.

- Local authorities which have set up their own complaints systems receive a substantial and steady number of complaints about planning issues.

- Academic projects have also revealed a widespread dissatisfaction with the system.

For the most part complaints to the Ombudsmen are about developments next door or development which upsets the balance of small communities. Of course, much of this dissatisfaction stems from the fact that the basis of the development control system is that planning permission should not be witheld if a proposal is in conformity with the development plans in force unless there are sound planning reasons why it should be refused. Such reasons can, in principle, relate to the amenity of individuals but more often than not they do not.

Many local authorities notify neighbours of development proposals which may affect them. This is very much notification rather than consultation. The views of neighbours on development proposals may be summarised for the elected members who have to take the decision. However, because of the way the system is constructed this comment is invariably negative. What is lacking is input of a positive kind about the way in which people view their environment and how it might change.

The move towards "consumerism"

In the last decade there has been an effort to make local government in Great Britain more "market orientated". This has been an important and fundamental refocus. The process started with an emphasis on value for money, an audit based objective, and proceeded from that to competitive tendering. Both have been worthwhile in improving the effectiveness of local government in terms of reducing cost to the consumer. A third element, that of "customer care", has been more honoured in the breach than in the deed. Quality standards assurance systems such as BS 5750 and ISO 9000 and more nebulous innovations such as the Citizens' Charter are either supply led or provide inadequate guidance about implementation. Even agencies such as the Local Ombudsmen that are introduced to ensure that Local Government operates in the "public interest" respond only to complaints and, therefore, measure levels of consumer satisfaction by default.

It is one thing to imagine what the customer wants and to organise services and manage change accordingly; it is another to find out what the customer really wants and to organise services and manage change on that basis. From the latter point of view the "market" can be seen as those people consuming local services but whose wishes should dictate change and the management of that change by local government. The free market provides only one example of this[1,2,3]. The situations about which local government is concerned are not always suitable for the application of "market mechanisms" as an instrument of "consumerism". We take a wider view of "consumerism" in which we focus on the citizen's agenda and criteria for services and change, and on the improvement of the measurement of "need".

The technical means are becoming increasingly available to elicit and articulate the views of the consumer, and to store and make available that information in an accessible form. It is a political matter whether effect should be given to these views.

The needs at the grass roots have always been difficult to identify and classify. This is why politicians have been able to generalise without fear of contradiction, at least by their constituents. The problem with the views of the constituents is that they are disaggregate and do not readily respond to attempts at identification, classification and articulation. Were it possible to obtain better information about the consumer agenda, and it will be suggested that it is, then these views could be the generators of change, and as such should be seen as the motivator of foreword planning systems rather than as a "sop to Cerberus".

Not only should it be possible to identify what individuals and communities think about their environment and its evolution, we should also be able to identify the degree to which they wish to influence change or to stand still. In other words, what are the attributes that are important to individuals and communities, and what is the attribute space within which they operate? Naturally enough such attitudes are continually evolving and their identification and classification requires the facility to obtain ongoing information about local change and the provision of a database capable of dealing with it in an accessible format. This will be considered later in the paper.

It is almost axiomatic that if effect were genuinely given to the views of the consumer it could have a profound influence on the nature of political representation at a local level. No longer could the local Councillor say "These are the views of my constituents" without fear of contradiction. At a national level this sort of detailed information about consumer views could bring into question the whole basis of the development control system in Great Britain i.e. that the system operates in the public interest but takes no formal account of the particular interests of individuals[4,5]. This point of view has prevailed almost unchallenged since the Urquhart Report of 1944, which laid the basis of the Town and Country Planning system in

Great Britain, and in one sense has been undermined by numerous decisions of the courts and the Planning Inspectorate where the interests of individuals have been recognised. The tension between the principle on which central government in Great Britain operates, the way in which the system actually operates and the increasingly articulated grass-roots view of what is needed has never been more acute.

The implications of this are considerable and varied:

- The political and institutional implications for local government that would result from an expansion of the statutory obligations to obtain and use information about consumer responses and requirements;

- The possibilities for improved consumer participation provided by developments in information technology.

- The introduction of multi-disciplinary dialogue to support improved information provision and interpretation. The diversity of skills required are not available to any single agency, neither do mechanisms exist for drawing them together as a common resource.

- The feasibility of a local, integrated and project-based (as opposed to task based) approach to local decision-making and service provision. i.e. Land use planning policy and the decisions based upon it invariably impact upon or are affected by areas of social policy such as housing, social services and education.

Local Government and Understanding Need

Local Government in Great Britain has undergone considerable change over the last decade. The main impetus in this change has come from Central Government and had two elements. The first was to some degree ideological. The Government wished to see value for money in the provision of services. The second strand was economic. The Government wished to reduce public expenditure and borrowing not just by central government but by all publicly funded bodies. It is often assumed that this was founded in enterprise culture. While this may or may not be so, the fundamental ideology of the process was to let the individual decide about the changes in their environment, and to identify the needs they considered to be important.

At all events the new broom led to the sale of Council houses, educational reform based upon parental choice, opting out for state schools, tenant choice for those who did not wish to buy their homes and compulsory competitive tendering. The same element of choice has been introduced in the health service and in higher education. All these moves have led to higher expectations on the part of the consumer. Attempts to elicit the degree of consumer satisfaction with this or that service have been sporadic and piecemeal. It is submitted that accurate and appropriate information about consumer needs are fundamental to local government (and indeed central government) irrespective of whether the services are provided directly or by competitive tendering.

The information obtained must represent the diversity of consumer opinion and not merely the concerns of those who are able and used to articulating their views whether in letters to The Times, through existing participation procedures, or elsewhere. There is, therefore, a culture of non-participation that must be addressed, and information provided about the needs that exist within that culture. Moreover, this information must be dynamic and not static. It must be possible to monitor change in consumer need. This will present a problem for local government which has still not entirely cast off its paternalistic and corporate origins. Traditionally local authorities have:

- Seen themselves as providers of services defined by statute.

- Adopted a technical and organisational perspective based on a professional bureaucracy and its inherent culture.

- Interpreted accountability simply as statutorily defined procedures.

Change in such a context is very much government led and ignores the fact that it is a two way process that is dependent upon an evolving and varied local response. This paper suggests that it should be recognised and managed as such.

The sources and effects of change are a very complex process in modern industrialised societies. The bureaucracies which administer these societies are not immune to new procedural ideas or structural change but are often slow to react to those forces that influence change from outside. In their monitoring and evaluation of change they tend to use inflexible and static performance measures which are often unsuitable for coping with uncertainty or unplanned change. For example, the way in which the public are invited to participate in the formulation and examination of Structure and Local Plans is highly formalised and tends to play to institutionalised opinion rather than the views of everyman. The external environment is often seen as hostile to the formalised processes of the bureaucratic system. Elected members of local authorities tend to take the same view as the paid officers i.e. they often exhibit considerable hostility to citizens who complain to the Local Government Ombudsman, because they are seen as hostile to "the system".

A number of arguments have been advanced in support of the "governors'" static and restricted view towards information about the needs of the citizen as a basis for managing change.

- Existing representation is adequate and equitable whether this is through elected members, pressure groups or formal participation procedure.

- It is impractical in terms of time and resources to undertake more extensive and frequent monitoring of consumer opinion;

- It is difficult to measure and interpret unstructured and often idiosyncratic responses.

- The complications implicit in dealing with such information would cloud issues and detract from the professionalism within the management system[6].

There is the problem, therefore, that established organisations and especially, perhaps, established organs of central and local government are congenitally ill-disposed to reorganising themselves to adapt to external change and ill-equipped to handle information for which they are not already "tooled up". The duties of local government and the activities which those duties entail are, by and large, settled by Parliament and Central Government. (It is not the purpose of this paper to suggest that those duties should be different.) They are, of course, performed in a diversity of ways but are hierarchically determined rather than by the consumer. This is nowhere clearer than in the field of land use planning where the legislation, while recognising the need to take account of social factors in the planning process, has never really grasped the nettle of how to do it let alone advise the practitioner on the means. The consequence is that the physical land-use aspect of planning is exaggerated at the expense of the social on which consumers might be expected to comment more readily. The system does not therefore address individual citizens' concerns about the quality of life and their values in relation to the environment[7,8]. To summarise, land-use planning fails to respond to the consumer in the following ways:

- The recent history of planning in Great Britain has witnessed some changes in the process and in the presentation of the system e.g. public participation in Structure and Local Plan formulation and latterly a requirement to notify neighbours of planning applications which may affect them. However there has been little reappraisal of the role, purpose and scope of the planning system and its impact on the environment generally.

- Even though development plans can be monitored according to socio-economic and cultural criteria, inadequate procedures exist for this to be undertaken efficiently.

Individual decisions at local authority level are only assessed on land-use criteria and project completion.

For all the reasons that have been advanced the relationship between the consumer and the planning system is reactive rather than proactive.

At present local government takes little note of the complex reaction which its actions i.e permission for a new housing development or a change in service provision, can evoke. Why should they take note? One fairly obvious reason is so that local government can avoid making the same mistakes twice. More important, perhaps, if the proper techniques for sounding out local opinion had been in place mistakes would not have been made in the first place. It is submitted that local government needs to proceed from its present sources of knowledge about the views of its consumers to a new knowledge base which will provide it with richer information. It is also suggested that the opportunity to provide information on an ongoing basis about how change is perceived in the language of the consumer will help to demystify local government, especially in the sphere of land-use planning, and encourage a more proactive role by a population which traditionally has not participated.

Pathways and Change: an example of an Elicitation Technique

Before pursuing the implications of providing more appropriate and accurate information to local government about consumer attitudes the scene can be set by describing some work which has recently been carried out at Cranfield Institute on consumer reaction to changes initiated by local government[9]. A project was designed to provide an insight into how change was perceived on the one hand by the local authority and on the other by the community. A small village was selected and a 10% household sample was interviewed about the causes and effects of changes in the village over the previous ten to fifteen years. A "pathways elicitation design" was used which allowed respondents, without any prompting, to pursue the causes and effects of changes which they had previously cited as important. The responses were analysed according to their constituent interactions i.e. first, second and third level causes and effects of the cited change. Three general characteristics were observed in the responses:

- Respondents became considerably more aware of the non-local and structurally distant causes and effects of change i.e. central government policy, and regional residential and employment mobility

- Attention became focussed upon the less concrete manifestations of change i.e. changing attitudes, lifestyle and policy

- The physical and social attributes of change were seen as interdependent i.e. changes in the village social structure were significantly affected by a new housing development which in turn was a response to the demand for new housing that had resulted from regional demographic change.

This research showed that:

- Individuals are capable of identifying the linkages and patterns of change that affect both themselves and others.

- These patterns can provide information for decision makers about the variety of levers for effecting and adapting to change.

The development of techniques for eliciting information about consumer attitudes goes hand in hand with advances in information technology and offers two advantages for local government.

(a) It is becoming increasingly possible to establish integrated data bases that can link the descriptive attributes of an area e.g socio-economic grouping, distance from urban centres, and population density with the characteristics of a planned project i.e. the number of dwellings to be built, population increase and age distribution. This can be compared with the quantitative outcomes of the project, such as the use of local schooling, and the qualitative evaluation of the change i.e. the perceived effect on the community in terms of access to the new development for local people and changes in local service requirements. In this way one can begin to identify the unanticipated consequences of specific projects and can assemble a cumulative data base showing patterns of qualitative and quantitative interaction. The development of Geographical Information Systems (G.I.S)[10,11]is already well advanced and provide a basis around which to develop complementary Social Information Systems (S.I.S.) of primarily qualitative data.

Access to such a database need not be restricted to individual authorities or service providers. It could inform decision makers in other localities and central government but more importantly could be used to provide information in support of an integrated and adaptive approach to decision making and project management. This would be especially useful for land use planners whose basis for decision making would be greatly broadened.

(b) Advances in information technology could make it possible for the majority of the population to have their response to change through local authority activity recorded. Home based technology will assist in this but the establishment of local consumer response centres (mobile if necessary) could provide information about specific projects e.g. a major planning application and enable the public to record their reaction. Such units could be located within existing facilities such as libraries and mobile libraries as well as local post offices[12].

In this way a considerable body of consumer reaction to a variety of issues would be available. Who should be responsible for obtaining this information? Should the responsibility be independent of local government? It is always tempting to look at existing institutions. Bodies which are practised in canvassing the public include the Consumer

Council and the Office of Population Censuses and Surveys. Other possible contenders are the Audit Commission and the Local Government Ombudsman.

For every such extension of activity there is a cost though sometimes there are cost savings in better decision-making. It is possible to make tentative estimates of the magnitude of costs. There is already information technology (IT) within local government. Recent information(13) shows that current (IT) expenditure per head of population is in the range £15 - £20 per head of population per annum. The additional cost of handling a consumer information data base is marginal, perhaps £5 per person. Obtaining information from the population might cost perhaps £10 (given known costs for specialist in-depth attitude surveys) giving a total of £15. Specific projects might require additional one-off local effort. A figure of 1% of project budgets has been suggested, at least an order of magnitude less than the market research and marketing costs of commercial products and services.

To place this level of costs in perspective the cost of handling a complaint about local government by the Local Government Ombudsman is now approaching £400. The remit of the Ombudsman is somewhat specialist but this latter figure serves to emhasise the relatively modest costs of the proposed consumer information which would, if allocated to the local government IT services, double the IT budget to around 6-10% of total revenue budget.

Discussion

The thesis of this paper is that a proper provision of consumer services especially within a market economy depends upon an accurate evaluation of consumer need. It is also argued that this appraisal should not be made by the providers of the service. Such assessments should be used to inform the management decisions of the providers and indeed they should be obliged by statute to take them into account in making decisions. It is also argued that there can be no proper integrated planning and management of change without such a system being in place. If this is accepted then it seems inevitable that the management structure of local authorities would have to change so that consumer response can be evaluated properly and the evaluation fed into the decision-making process in a coherent way. This would have a profound effect on the present corporate and hierarchical work pattern of local government. There would have to be a broad integrated management approach to specific projects which would include the provision, interpretation and response to information about consumer satisfaction.

Three central features of such a restructuring can be identified:

- A greater choice about the direction of change would increase the potential for consumer based information to assist in its planning and management;

- Planning would refer not only to service provision but to the need to provide a response to the problems and concerns of the community;

- Local government would be more accessible both in geographical and procedural terms. Individuals would become more confident about assuming ownership of the local agenda if their access to local government was not hindered by technical language, restrictive criteria and a bureaucratic culture that may also be spatially distant.

The ongoing provision of information, in the language of the consumer would, therefore, not only result in better informed and responsive local government it would also affect power and representational structures by making them more diffuse and less prone to domination by minority interests.

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Social enquiry and the measurement of natural phenomena: the degradation of irrigation water in the Argolid Plain, Greece

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SUMMARY

Attempts to formulate appropriate policies for the management of agricultural systems are constrained by the limitations of acquiring information about changes in the natural system across space and through time. The adoption of natural science techniques to measure the transformation of natural phenomena requires considerable investment in time and expertise and may not always be capable of providing information about change in a way that meets the adaptive requirements of planning and policy. A more flexible approach to data collection will require the acceptance of less precise and more general physical data as the basis for understanding changes in complex agricultural systems. This raises interesting questions about the adoption of social enquiry techniques to provide information about changing natural phenomena. The progressive deterioration of water resources, as a result of intensive agricultural activity in the Argolid Plain of Greece, will be considered and the problems of measuring the extent of that degradation, and the processes leading to it, will be discussed.

INTRODUCTION

It may be axiomatic to state that agricultural systems are ever-changing and complex and, as such, decisions and policies relating to them must be based upon an informed understanding about the transformations and interactions that constitute them. Extensive discussion has taken place about the nature of these interactions, in particular what is becoming recognized as the 'seamless web' between social and natural phenomena (Lovejoy and Napier, 1988). This discussion has accompanied an approach to agricultural systems which attempts to integrate biophysical and socioeconomic subsystems (Stomph *et al.*, 1994) and a growing sensitivity to the social shaping of agriculture (Buttel, 1989). Social enquiry techniques are increasingly being employed to evaluate the likely response of key actors to particular policy instruments (Potter and Gasson, 1988; Ibery and Bowler, 1993) and to investigate their receptivity to information and the criteria which may lead to the adoption of various technologies (Seaton and Cordey-Hayes, 1993). There is even increasing support for the

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social science paradigm to be applied to the study of natural science itself (Newby, 1992). This paper will focus upon a simple but neglected component of this emergent synergy between natural and social enquiry paradigms, namely the ability of social enquiry to provide data which provide a realistic insight into the magnitude of specific natural transformations that affect and are affected by human activity.

SOCIAL ENQUIRY AND THE MEASUREMENT OF NATURAL PHENOMENA

What will be proposed in this paper rests upon a number of assumptions that may not be readily acceptable to proponents of traditional scientific enquiry (e.g. the use of approximate data). It is, however, seen as supplementary and not in conflict with such a paradigm. There is a clear distinction between data that provide some measurement of the extent to which natural phenomena have changed, and the process of scientific enquiry which is intent upon establishing the nature of such phenomena and the relationship between them. For example, information about the amount of salt in groundwater in different places and at different times does not inform about the impact of salt upon various soil types and cropping regimes.

Having made this distinction, it is necessary to focus upon the characteristics of monitoring or the measurement of natural phenomena. 'Good science' would assume that this is accurate to the *n*th degree and is undertaken according to standard scientific procedures, often requiring the employment of considerable technical expertise and accompanying technology. This traditional scientific model should be capable of providing an accurate picture about the state of a particular phenomenon at any one time. However, such a model has a number of limitations that restrict its value for informing policy. Firstly, technical and personnel constraints limit the number of measurements that can be undertaken, at any one time or over time. Secondly, this restricts the ability to obtain information about spatial variation. These limitations of scale mean, thirdly, that it is often impractical to provide data about the variation within an area and between areas. Finally, once a natural process has been identified as significant, it is often impossible to obtain historical data about it.

Therefore, a complementarity can be identified between the acquisition of relatively few accurate (assuming scientific proficiency) measurements which cannot readily inform about how that transformation contributes to the wider picture, and some alternative way of collecting and presenting data which compromises accuracy, but which can inform in a more responsive manner and over a broader canvas (see Conway, 1985). A basic assumption underpins the use of social enquiry techniques: that the key actors in any system not only respond to the system as they see it (Lemon and Park, 1993) but that they have a reasonable understanding of the degree of change in the natural world in which they operate.

For example, a farmer will be able to inform fairly accurately about the amount of water he or she uses, the changing flows and salt content of that water, and the depth at which it is accessed. The use of data from a sample of such farmers would enable the development of a picture of qualitative and quantitative change over a wider range of temporal and spatial scales than would be possible from the technical measurement of individual bore-holes over time. It is, of course, essential that some technical measurement is undertaken to validate (or otherwise) the data obtained from respondents. What emerges, therefore, is a database that has different levels of definition appropriate to a range of functions (Table 1).

The effectiveness of the social enquiry approach may be compromised when the phenomena to be measured are subject to statutory control and have an explicit compliance incumbent upon the respondents. This factor may make access to respondents more difficult, and where there is a willingness to respond it may raise questions about whether realistic data can be obtained concerning activities that might implicate respondents with non-compliant behaviours. Work undertaken in Greece, and discussed below, had to be handled sensitively to overcome an inherent scepticism among farmers towards questions which referred to farming activity. This scepticism was magnified when addressing issues that were felt to have possible repercussions for the respondent (i.e. the extent to which controlled water was used).

Table 1 Investigative approaches and levels of definition

	High level of definition	*Low level of definition*
Approach	Technical experiment/monitoring	Social enquiry interviewing
Scale	Local, incremental	Wider scale, process
Purpose	Scientific investigation of natural phenomena, validation of elicited data	Investigation of complex interactions, provision of questions for technical enquiry

The benefits derived from the adoption of social enquiry techniques relate to the data collected from respondents, not only in terms of their knowledge about specific levels and transformations, but also through the provision of access to phenomena that previously may have been inaccessible. This access is particularly useful for undertaking detailed measurements of phenomena that cannot be located through other means. For example, in the Greek study, attempts to locate bore-holes, in order to monitor hydrological change, proved particularly difficult. The search and measurement was carried out using non-local geologists who were unaware of the social habits of the farmers (i.e. when and where to locate them) and were not trusted by them. These problems were eased considerably with the introduction of local agronomists who were known and trusted, and who were prepared to interact socially with the farmers. Data were subsequently obtained about both the hydrological condition of specific bore-holes and about the water use of the farming community in general.

This example will now be developed to show how social enquiry techniques were adopted to provide information about the degradation of the natural resource base in the Argolid Plain, Greece.

BACKGROUND

The Argolid Plain is situated in the Peloponnese, approximately 150 km south-west of Athens (Figure 1). It extends around the towns of Argos and Nafplio. The total area (*ca.* 1100 km^2) comprises mountains (38 600 ha) hills (26 500 ha) and valley bottoms (42 000 ha). The valley itself is subdivided into 29 500 ha of cultivated area; 7800 ha of pasture; 3000 ha of urban surface; and 1750 ha of uncultivated land. All of the

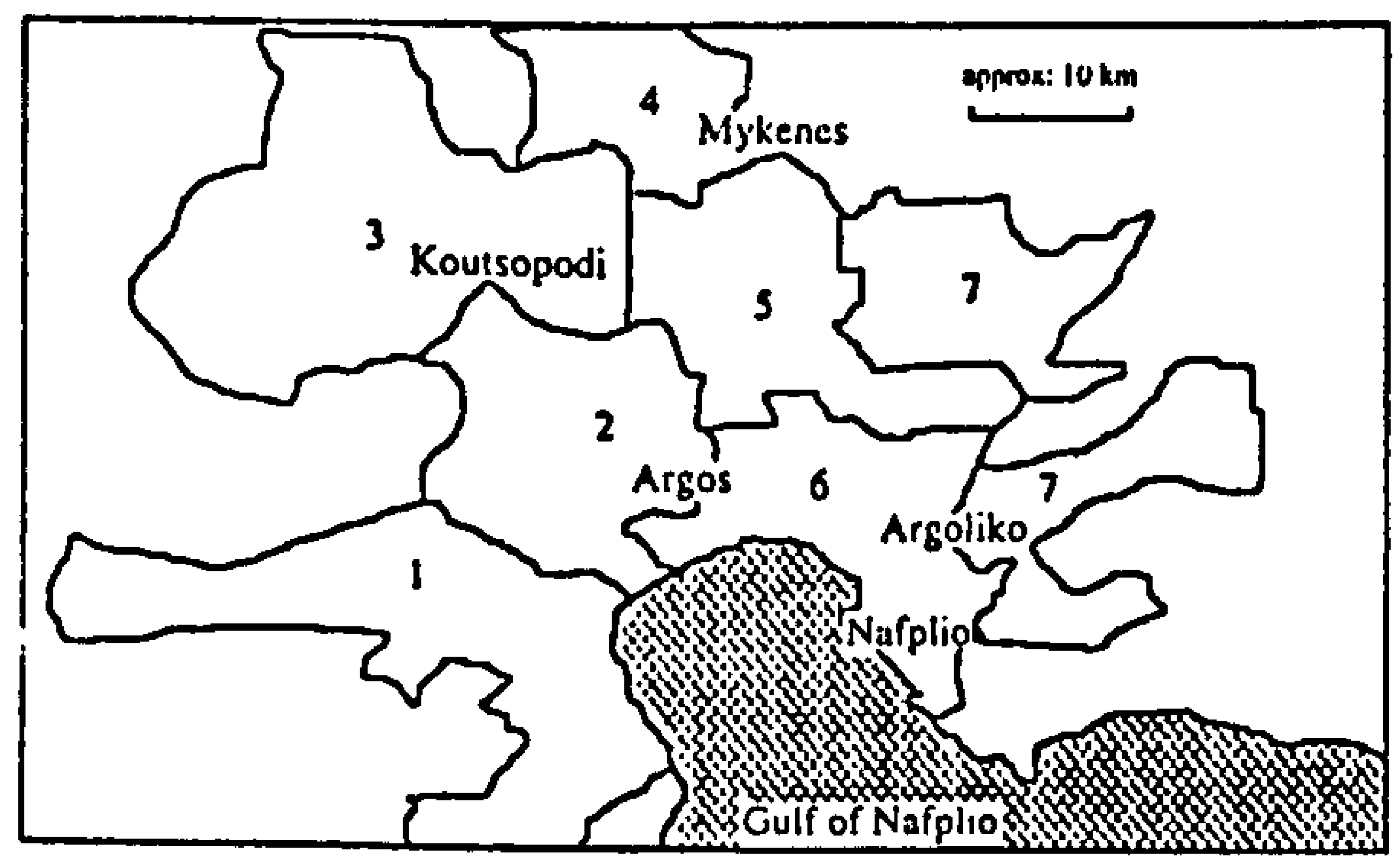

Figure 1 Outline map of the Argolid Plain study area and analytical zones (numbered) adopted for analysis. The areas in zone 7 are not contiguous and have been analysed together

streams feed at the edge of the valleys into underground aquifers. The soils are generally stony on the hillsides and of poor irrigability. Deep soils (silt, loams and clays) make up the majority of the irrigated area (approximately 120 km^2). Local agriculture has changed from the dry cultivation of cereals and olives alongside some vegetable growing and sheep/goat herding, to the current predominance of fruit production, in particular oranges (Table 2). This shows the marked decline in non-irrigated cereal crops, generally grown for domestic consumption, and their replacement by irrigated fruit crops for which there has been an expanding market. This change has been particularly evident since 1981, with accession to the European Community and the introduction of various forms of price support and subsidy.

The region has also witnessed a growing tourist industry which has taken two distinct forms: first, that which is based upon the cultural heritage of the area, specifically the ancient sites of Mykenes and Tiryns and the town of Nafplio; and second, the 'sea and sun' areas, particularly around the resort of Tolo. At present, tourism does not

Table 2 Main agricultural crops in the Argolid Plain (figures in hectares). (Source: Greek national statistical service)

Crop	*1964*	*1972*	*1980*	*1986*
Citrus	8119	10 452	9482	10 784
Orange	6487	8356	7469	8733
Non-citrus fruit	508	1076	1688	1853
Olives[1]	2449	2600	2885	2852
Cereals	16 464	10 961	9469	7174
Irrigated land	17 155	17 414	18 045	18 968

[1]olives are recorded in 1000 trees

compare with agriculture as a user of natural resources (i.e. 89% of water is used for irrigation and only 6% in total for human consumption) or as a local employer. However, as agriculture undergoes increasing stress (through the reduction of price support and the higher costs attached to farming), and the tourist industry continues to grow, it is anticipated that the competition for natural resources will become more acute, particularly in the summer months.

The intensification of agriculture, with the accompanying increase in mechanization and fertilizer and pesticide use, has led to a critical level of degradation in the quality (salination) and availability of water, and the progressive degradation of soils.

> During the last thirty five years groundwater has almost been exhausted, polluted and contaminated, the soils are in danger of degradation and even the quality of spring waters has deteriorated. Argolis today is not just poorer than in the past, but it follows a degradation path that may ultimately lead to desertification [Agricultural University of Athens, 1993].

This degradation path is both quantitative, with bore-holes in the area reaching 400 m in depth (with increasing uncertainty about reaching water) and qualitative, with salinization occurring primarily because of sea-water intrusion into the valley as groundwater levels drop (see below).

The current irrigated area in the plain is over 20 000 ha, with 95–125 million m^3 of water being obtained from wells and bore-holes each year, the remainder being accessed from springs and transported via specially constructed pumping plants and aqueducts. The water is used not only for ground irrigation during the drier parts of the year, but also to protect the citrus crops, particularly oranges, from frost during the winter months. Irrigation is primarily undertaken using sprinkler systems, although a significant amount of flood irrigation remains. Protection against frost is carried out using sprinklers; air mixers are also used to protect against frost, but these are expensive to purchase and maintain and have only a limited impact across the region. The use of sprinklers may well provide one reason for the relatively static water input per irrigated unit over the last 40 years (Table 3) when the employment of improved irrigation techniques should have indicated a reduction in that figure.

There is a general local consensus that the natural resource is being degraded. What is less clear is the extent to which this process is taking place over the area as a whole, and the degree of local variation. Data to support this trend are restricted to a small number of technical monitoring stations (i.e. on depth, flow and salt content of bore-holes) that are in place to support experimental work on a range of technological solutions – in particular the replenishment of aquifers with spring water.

Farmers require a licence from the Service of Agriculture to open a bore-hole which must be presented to the electricity company before any connection is made. A rough estimate of the number of new bore-holes can be obtained from this source, but it gives no information about the history of the bore-holes – namely about where they may have ceased to function or on those that were in existence prior to the licence requirements. It neither informs, also, about the irrigation practices of the farmers, the change in flow of the bore-hole, or the chloride content of the water.

The manner in which water-based technologies are utilized is particularly important when the

Table 3 Estimated expansion of irrigated agriculture

	1945	*1965*	*1985*	*1990*
Irrigated areas (ha)	5500	12 500	17 000	19 500
Total water applied ($\times 10^6$ m^3 year^{-1})	45	100	135	145
Water applied per hectare (per year)	8181	8000	7941	7435

water used is not monitored. Bore-holes that are independently or collectively owned obviously draw upon a common groundwater source, but there is currently no method of monitoring or restricting the use of water. This is not the case with irrigation water, which is supplied from the canal infrastructure and which is regulated by the local authority. The adoption of sprinkler systems provides a key example of the need for more data relating to water use, and thereby the extent and nature of depletion and degradation. In the summer months, the sprinkler technology undoubtedly offers a more efficient use of water than flood irrigation, but the area experiences considerable problems with frost, particularly in January. A common perception is that frost has increased where there is intensive growing of fruit trees. This is thought by the local farming population to be due to the raising of humidity in these areas. It is an accepted practice that artificial rain or sprinklers are employed to raise the air temperature around trees to prevent frost, but no data exist about the amount of water that is used to support this practice. The problems arising from this issue are well-documented from an interview with an agronomist from the Department of Land Improvement (YEB):

> To make our (farmer's) life easier we start the sprinklers at 0°C or even 1 or 2°C, so that we do not have to get out of bed or so that we can play cards in the cafe without being disturbed. Some sprinklers may well work unnecessarily for the 100–150 winter nights when the temperature drops to 1°C.

Similar points were made in a seminar on the Argolid water problems run by the Association of Agronomists for the area:

> Floor question: 'Farmers are using artificial rain in winter for protection against ice; however, the problem of ice only arises occasionally. The rest of the time the water is used needlessly'.
> Response: 'The use of artificial rain does protect the plant against ice; however, if it is being used at times when there is no ice then I do not know what to say' [Association of Agronomists of the Argolid, 1992].

These insights highlight the two central issues which support the adoption of qualitative techniques for providing information about changes in natural systems. First, they indicate the need to understand the criteria upon which irrigation decisions are made. This understanding is fundamental to the development of an effective management strategy and highlights the limitations of focusing solely upon technical solutions without paying adequate attention to their social context. The second point, on which this paper is focused, raises the need for improved information about how much water is used as a result of this behaviour, at what time of year is it used, and how is it distributed throughout the region. It is only through a better understanding of this spatial/temporal distribution and the spatial context of degradation processes that any coherent plan can be developed. Several reasons can therefore be identified to support the social enquiry activity undertaken in the Argolid. In the first place, many of the dynamics affecting the choice of crop and crop management by farmers were liable to change more rapidly than the speed at which some aspects of scientific work could progress. Secondly, farmers work within a decision-space influenced by policy of some kind, and there are likely to be possibilities for change which do not necessarily use only scientific or engineering 'solutions' (i.e. responses to economic, regulatory, educational and social policy instruments). Thirdly, the agricultural area of the Argolid is larger than could realistically be investigated using technical procedures (ongoing research into the hydrology of the area is being carried out by the Agricultural University of Athens). Finally, it is difficult for a scientific research programme to sustain the same level and type of measurement over decades. Athens University has had some active role in the Argolid for 30 years, but one important source of historic data has remained untapped – namely, the farmers themselves.

ENQUIRY PROCEDURES AND TECHNIQUES

Two phases of interaction with farmers took place sequentially. Thirty exploratory interviews were undertaken to establish what information a more structured and systematic survey might reasonably be able to produce. It was apparent that farmers were not only aware of the costs of much of their activity, but knew quite accurately how much (in the case of water and fertilizer) they were using, when they used it, and why they did so. This phase made clear which physical and technological features of farming needed investigation and established a perception about the changing state of the natural resources in the area. This information was of particular relevance, given the conceptual model of the range of environmental and agricultural policy instruments that the farmers encounter when making farming decisions (based upon the first set of interviews with farmers and further discussions with agronomists, hydrologists and researchers active in the area).

The need to provide data about this spatial and temporal variation, and the difficulties encountered previously in identifying bore-holes, acquiring behavioural data from farmers and the technical/personnel restrictions of extensive measurement have all been seen to indicate the need for a different approach to data collection. The need is particularly evident when one considers the importance of historical data about water use, in relation to its scarcity. If we make the assumption that farmers have a reasonable appreciation of the water they use, it is not unreasonable to assume that they can also supply us with a history of the hydrological activity on their land. This assumption was also supported by the fact that 35% of the farmers were over 50 years old and that much of the land had been passed down within their families. It was realistic, therefore, to assume the existence of fairly accurate local knowledge about water use for a period of 50 years or more – the period over which irrigated agriculture has evolved.

For the second phase of the investigation, approximately 10% of the farming population across the Argolid Valley was interviewed (203 interviews, carried out in 39 villages) about the history of water use on their land and about their current farming activity. This phase was designed around the information requirements of the scientific community and those features of the agricultural system that were considered to be important by farmers, both of which were established in the first phase. The interviews were undertaken by two agronomists who had already established a good relationship with the farming community whilst co-ordinating a European Community (EC) programme for the Service of Agriculture. It was made clear that all information was to remain completely confidential, in order to allay fears about the possibility of the EC or local tax office receiving personal information. The interviews were carried out mostly in local cafes or bars, which had the effect of 'snowballing' responses, once it was clear that trust had been generated with one or two respondents. It also meant that the interviewers required considerable stamina for the sessions could last 5 hours and stretch well into the early hours of the morning.

The questionnaire upon which the interviews were based had three main sections addressing the structural, productive (economic) and irrigation characteristics of agriculture in the Argolid. Structural data were collected about farm size, the number of parcels of land farmed by respondents, and their age, gender and other income-generating activities. Information was also obtained about the breakdown of activities on the farm and the employment of seasonal labour. Production data referred to the crops grown by farmers, the prices they received and the markets to which they sold. Results relating to the structural and production characteristics of agriculture in the Argolid have been reported at length elsewhere (Allen *et al.*, 1994). For the purpose of this paper, however, the data collected about irrigation and agricultural water use and the degree of salination in the area are the principal concern.

COLLECTION OF DATA ON THE WATER/SALT SYSTEM

Relevant questions that were put to the farmers about water use in this phase of interviewing have been listed below.

(1) Last year did you use artificial rain, free-flow or both for irrigation?

(2) How many times did you irrigate this crop last year?

(3) For how long did you irrigate each time?

(4) What is the rate of water flow for this irrigation?

(5) Did you use artificial rain against frost/ How often?

The first of these questions differentiates between the more technically sophisticated method of irrigation using sprays and the more traditional method of periodic flooding. Irrigation specialists have much advice about the comparative merits of different techniques with respect to efficient use of water (Van Tujil, 1993). There is also a difference in equipment costs. In other parts of the Mediterranean, where water is explicitly priced, even more sophisticated equipment is used to administer doses of water directly to the root systems of many crops.

The next three questions (2–4) enable the amount of water used for irrigation to be estimated and totalled for villages, crops and zones. Seven zones were established for modelling purposes to provide a spatial representation of the data across the region. These were the result of an extensive discussion with local agronomists and were based upon land-use (crops), topography, water quality and availability, and frost levels (see Figure 1). These data also enable an independent comparison with data derived from hydrological measurement. The final question (5) was stimulated by reports of increases in the use of fine sprays during nights of potential air frost and a lack of data about how extensive this activity was.

A further question was included: 'From where did you obtain the water for this irrigation?'. Because of the highly dispersed nature of the farms, there is clearly a need to relate the sources of irrigation water to the plots of land upon which it is used. The various sources have different costs, variable quality and variations in the amount available. Because water itself is not, in general, priced, the costs that farmers experience are represented through the costs of access.

The next series of questions was as follows:

(1) If you have bore-holes, how many do you have?

(2) How deep are these holes?

(3) Do you own these yourself? With others?

(4) What is the flow from these holes?

(5) When (date) did you first use your own bore-holes?

From the 1930s until the 1950s, irrigation water was obtained mainly from conventional wells. As the water tables in the aquifers dropped from the 1960s onwards, and drilling equipment became available in this part of Greece, farmers began to drill deeper for water. The cost of water from bore-holes is a function of the capital cost which is, in turn, a function of depth, and the operating costs of pumps (mostly electric) which are, again, functions of depth and available flow. An additional cost arises when bore-holes are drilled and fail to yield water, or when the failure of an existing bore-hole precipitates the need to drill another. In some cases, bore-holes have become so salinated that the water has ceased to be usable for irrigation.

The interviewers were able to obtain information on virtually all bore-holes owned or used by farmer respondents and to identify when they were first drilled, their depth, the initial flow, and whether and when they had failed, and why. As a consequence, it has been possible to analyse these data to develop a strategic water-use and water/salt model over the last 50 years. This model can be compared with the hydrological data already obtained for the area.

WATER COSTS

Farmers were asked: 'How much did you spend on water last year?', a question that enables the distribution of water costs to be related to water use, and: 'When you started using your existing water sources, what was the level of salt [in parts per million (ppm)]?' The yield and quality of citrus crops is reduced as the salt content in irrigation water rises above about 450 ppm. This information, along with the dates when bore-holes were first drilled, enables a picture of the spatial and temporal distribution of salinization to be developed. Salinization is the main concern in many parts of the central Argolid plain, and salt content can exceed 9000 ppm. Farmers generally had good factual knowledge about the process, which was first evident as long ago as the early 1960s.

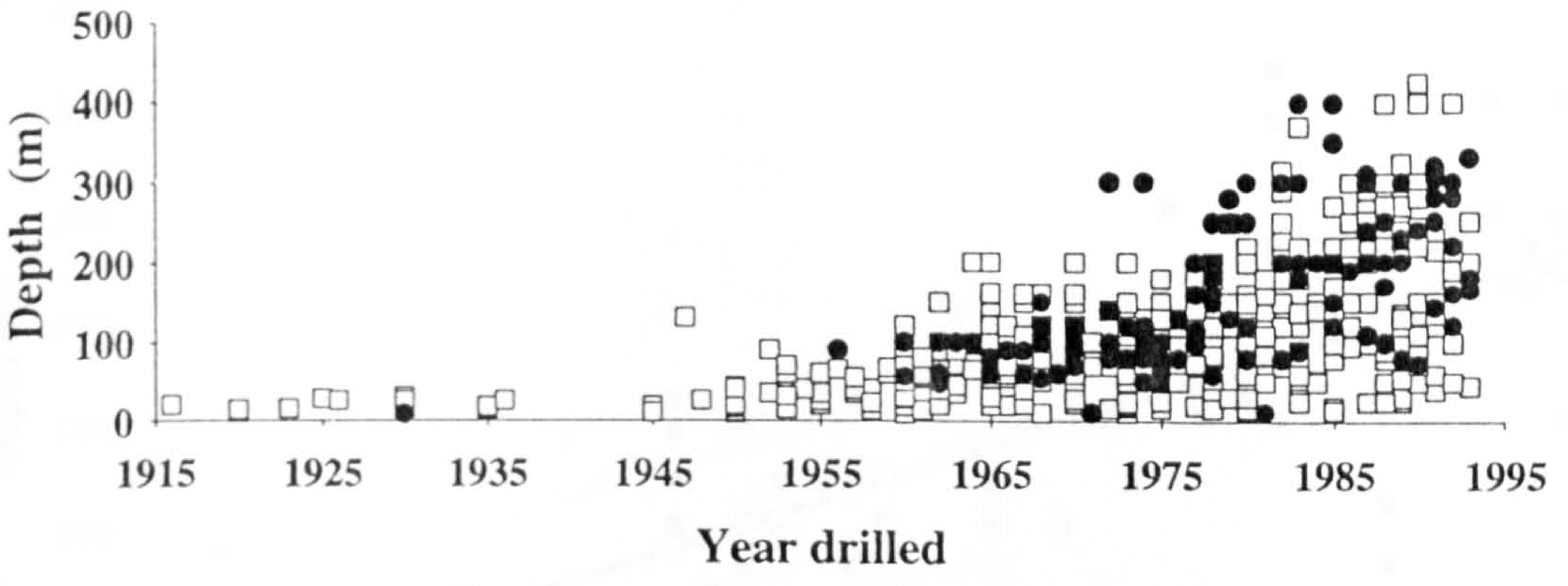

Figure 2 Depth and success of wet (□) and dry (●) wells/bore-holes

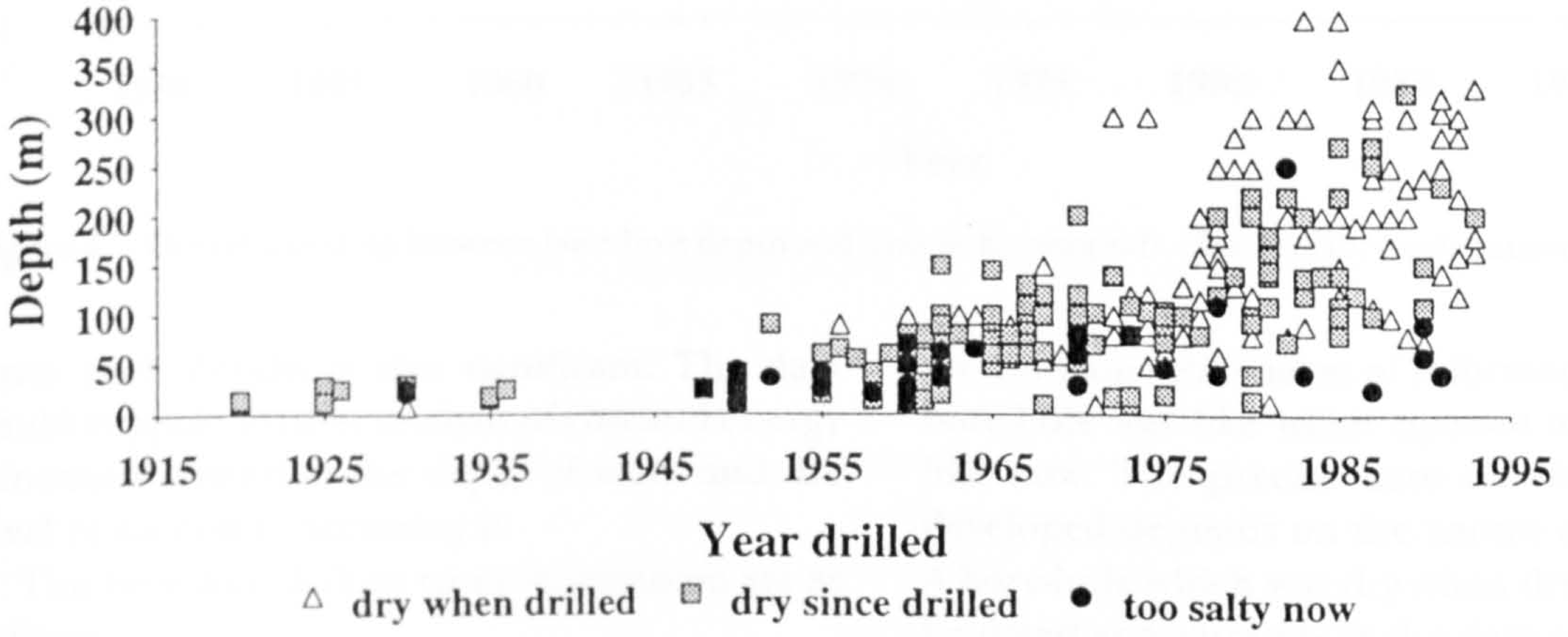

Figure 3 Failures in wells/bore-holes

THE WATER AND SALT PROFILE OF THE AREA

Analysis of the data collected from farmers has indicated the extent to which water has become more difficult to obtain in the region. For example, Figure 2 shows the distribution of the change in depth of bore-holes over time, with data separated into those bore-holes which provided flow when drilled and those which were dry when drilled.

The most striking feature is the change in depth over time. Since the mid-1960s there has been a marked increase in the depth of bore-holes, whereas, during this earlier period, the natural recharge more or less balanced the extraction of water. Most of the extraction up to 1950 was from conventional, wide-bore wells (some of which were horse-drawn) in the central plain and in areas close to the sea. Thereafter, there is a steep increase in depth and a marked increase in the number of bore-holes which were dry when drilled, although there are still some successful, shallower bore-holes and a broader spread of depths, even for those which are dry upon drilling. The more recent data suggest the influence of a number of factors outlined below and represented across the region by Figure 3. First, there has been a spread of irrigated agriculture from the flat and low central plain into the higher peripheral areas. (Hence the subsequent need to analyse the data spatially, and thence by altitude). Second, there was a reduction in the level of some aquifers with respect to sea level and an increased failure, at a given depth, of finding water in some areas particularly towards the periphery of the region. In some of these areas farmers may have given up trying to find water. The data suggest that, in other areas, particularly those at lower altitudes but further from the sea, farmers are still able to drill relatively shallow and successful bore-holes. Finally, it is remarkable that bore-holes in excess of 400 m have been drilled. Not only is the cost of drilling high (with the need for sophisticated drilling technology) but the cost of electricity for pumping

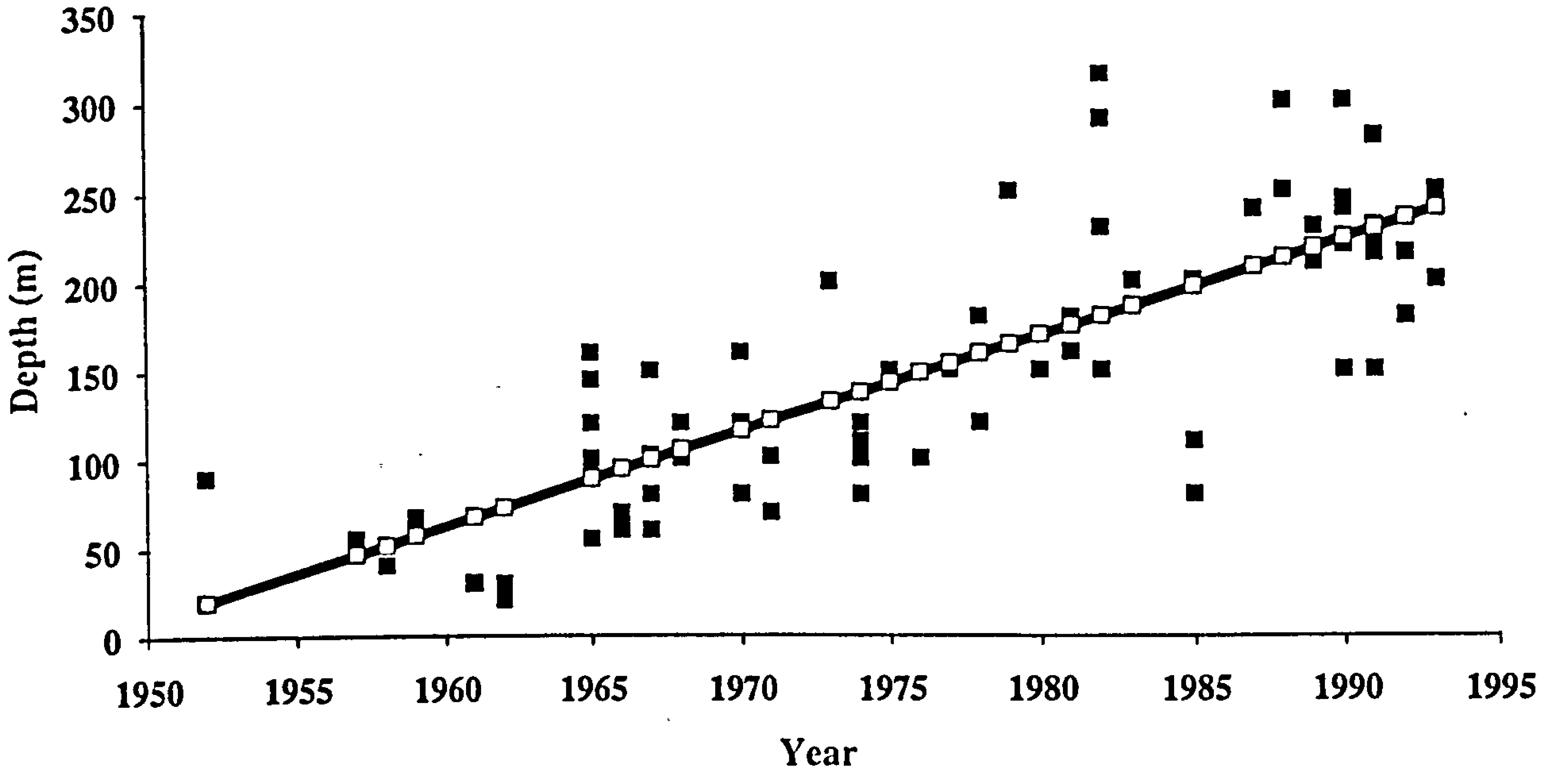

Figure 4 The relationship between bore-hole depth and time in Koutsopodi. (See text for explanation of data classes)

from such depths is also significant. The data could support further analysis of cost and energy functions related to the depth of water and the level of success in accessing it.

The bore-hole failure types represented are as follows:

(1) No change in flow.

(2) A reduction in flow, but not to zero.

(3) Reduction in flow to zero.

(4) No flow when drilled and no current flow.

(5) Too salty to use.

Those bore-holes with a reduction in flow are too few to be worth plotting as a separate group. The data shown on the chart incorporate the 'dry when drilled' bore-holes identified in Figure 2. The main trend here confirms the early data about bore-holes which have become too salty to use since they were drilled. After the early 1960s, the observations on 'too salty to use' bore-holes arise from the spread of seawater into aquifers in the main plain of the Argolid, as implied by the relative uniformity and lower depth of the bore-holes. As might be expected in a situation of progressive searching for water from aquifers that are becoming increasingly deep, the overall trend in unsuccessful bore-holes is generally at a greater depth than for those which have ceased to provide water since drilling.

It should be noted that the data are based on two fundamental pieces of information: what the bore-hole was like when opened and what it is like now. The precise date on when a failure developed depends on the nature of the failure. A bore-hole which was dry when drilled can only be dated as accurately as the data offered by the respondent. However, a bore-hole which has a reduced flow, or has become dry or too salty, could have done so at any time within the period between drilling and the present. No systematic attempt was made to encourage farmers to be more specific during the interviews.

VILLAGE ANALYSIS

The information obtained from the interviews was related to the village(s) in which the respondent farmed and thereby irrigated. Therefore, a useful analysis was possible for some villages where comprehensive data had been collected. It was also necessary to aggregate data across the region and into seven representative zones in order to compensate for those villages where adequate data were not available. Figures 4 and 5 illustrate the situation in two villages, Koutsopodi and Argoliko; each chart shows the distribution of bore-hole depth over time and the line corresponding to a least squares regression line relating the two variables. These two examples have been selected from the set of villages investigated to illustrate different depth and time

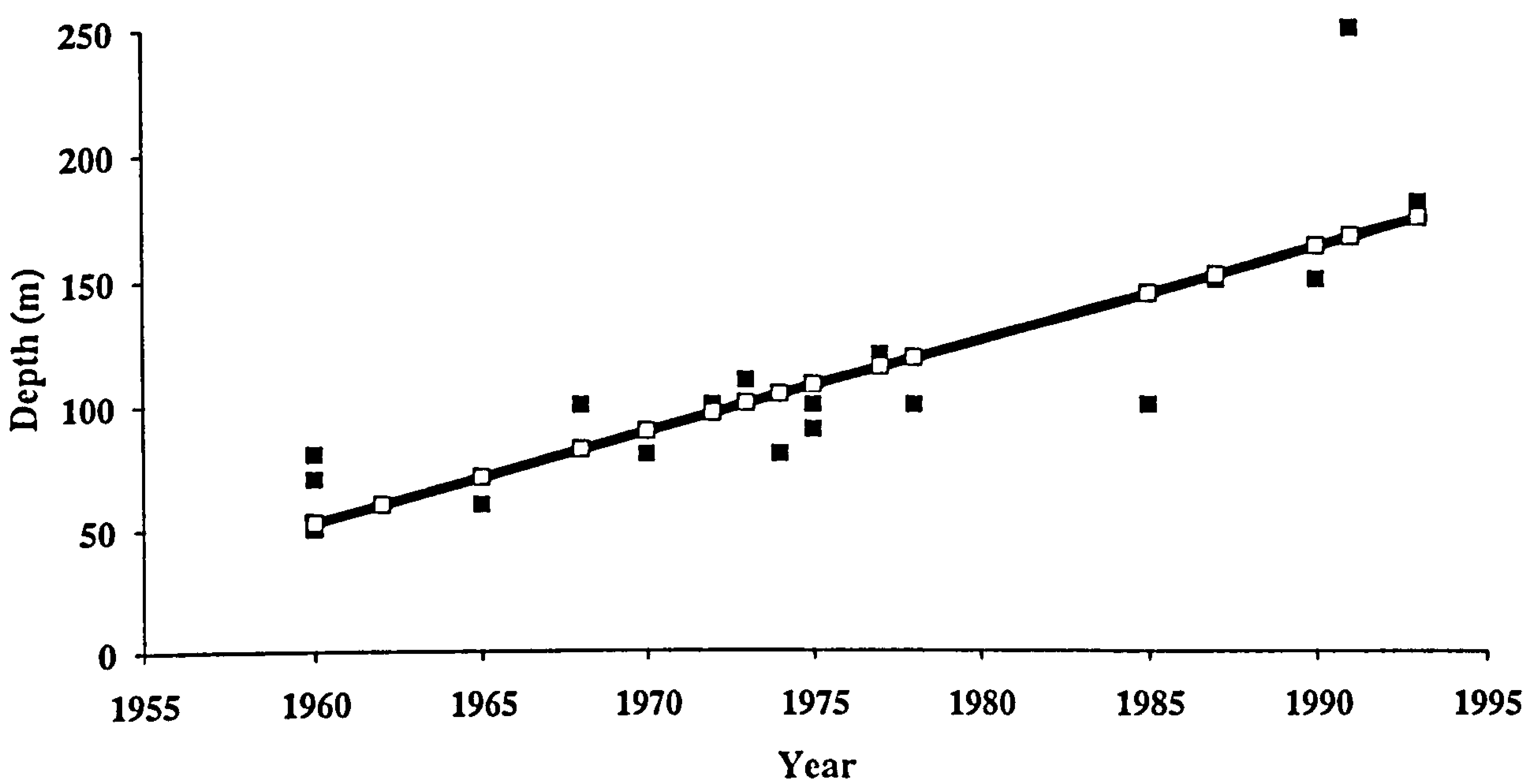

Figure 5 The relationship between bore-hole depth and time in Argoliko. (See text for explanation of data classes)

regimes. The black squares in Figures 4 and 5 are the original observations and the white squares (along the regression line) mark the depths estimated for the same year as each observation from regression equations. Koutsopodi is a relatively large and diverse territory consisting of a flat low plain, as well as parts of the surrounding valleys and hills. Fitting two separate lines to the data would be of value if the data on location were more precise. In Koutsopodi, apart from one observation in 1952, the earliest observations are from 1957 and continue through until 1993. Figure 5, for Argoliko, shows observations from 1960 to 1993, and represents a more recent move towards intensive irrigated agriculture than occurred in Koutsopodi, which was one of the first villages in the region to farm in this way. The change in depth is from 10 to 220 m for Koutsopodi and from 50 to 170 m for Argoliko, so that the average change in the former has been about twice that of the latter. It is the spatial variation in this rate of change which is of particular interest in this analysis.

Figure 6 shows the trends for those villages within the region for which there are sufficient observations. It should be noted that, as in the figures discussed above, the observations are for all bore-holes, regardless of whether they were initially failures or have become so since they were opened. The first main feature shown in Figure 6 is the enormous variation in the gradients of the lines, revealing large differences in the rate of change of the depths at which farmers have attempted to find water over time in different locations. Although some of this variation could be due to the altitude of bore-holes, the variations of the steepest lines are outside the range of altitudes measured on contour maps of the area. This is also largely true of the shallower lines which are associated with villages in the flatter areas of the central plain close to the sea. The range of depths also varies substantially between villages. For one village to show changes from 20 to 300 m over 30 years, and for another to show a change from 10 to 30 m over 70 years suggests some interesting physical and spatial dynamics. A second feature to note is that many of the steeper gradients have starting dates later than those with lower gradients, and a number of them end at earlier dates. In part, this variation may be due to 'sampling' limitations, i.e. the survey did not contact a comprehensive enough range of farmers in certain communities. It does, however, suggest that there is a time-dependent spread of irrigation from bore-holes from lower-altitude villages to higher-altitude villages. In the Argolid, this effect would correspond to a spread from the inner plain to the outer plain, and thence to the peripheral higher-altitude and hillier areas.

Figure 7 represents the proportion of failures

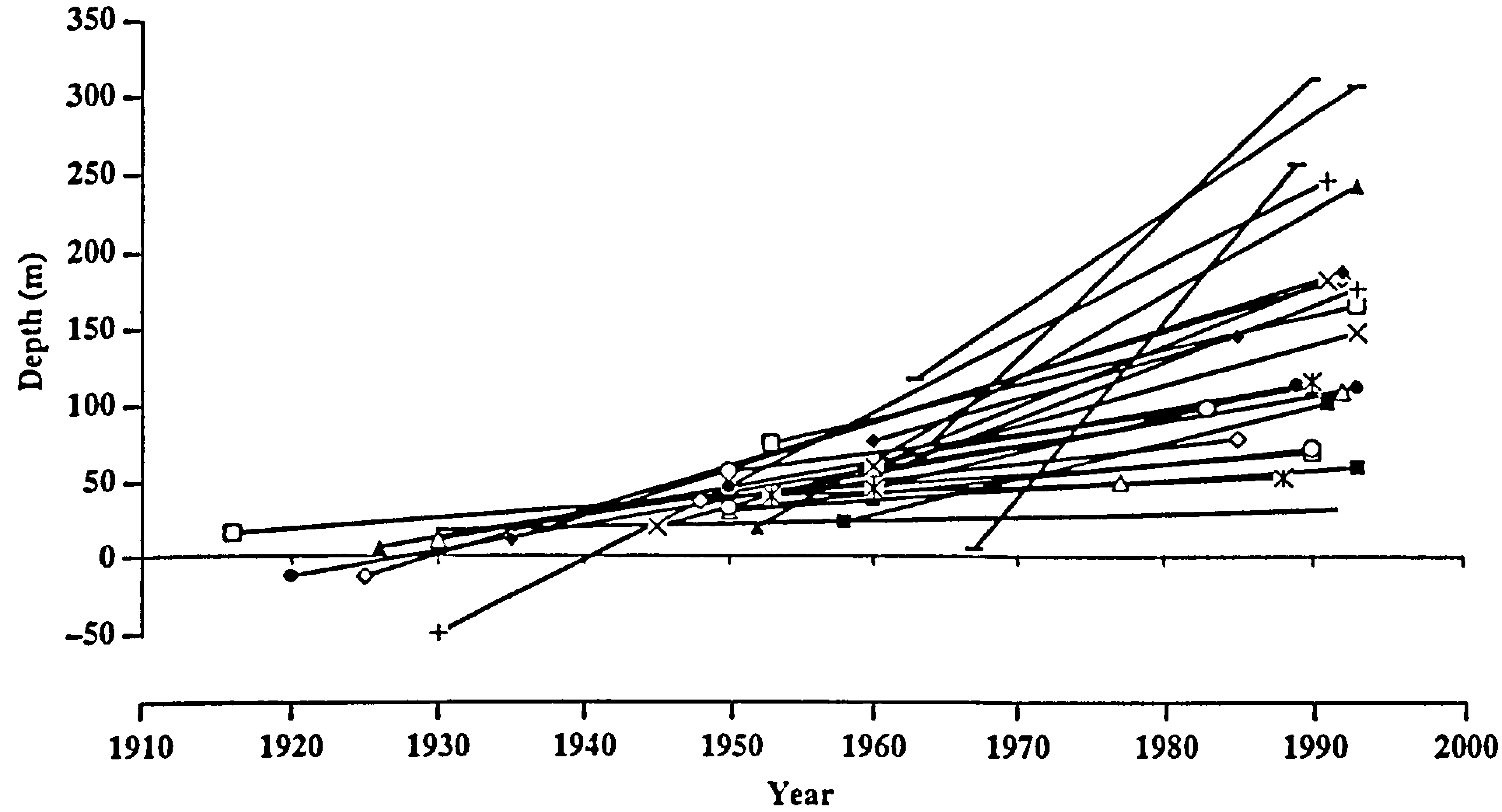

Figure 6 Regression lines for bore-hole depth and the date first used. (Data for all villages)

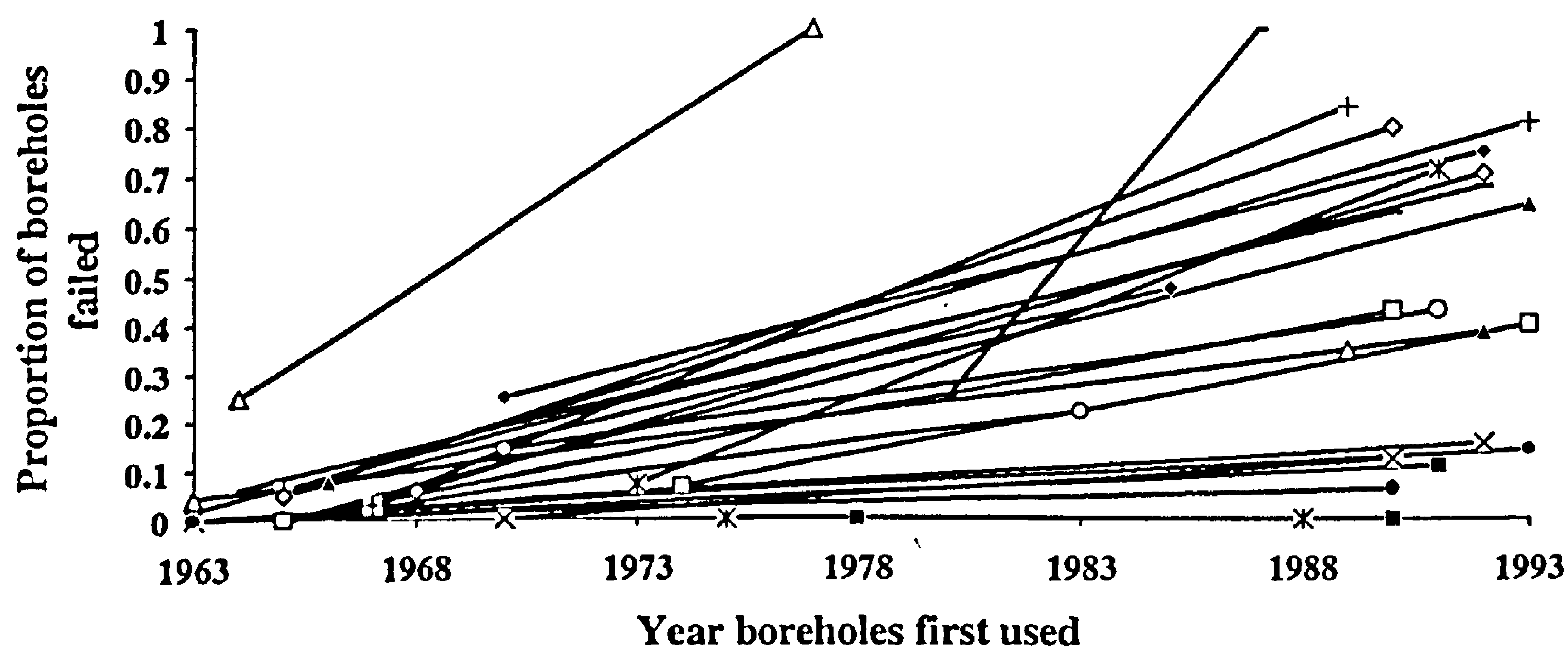

Figure 7 Failed bore-holes as a proportion of the total, in relation to first-use

in each village at the time of the first and last observations. These are connected with a straight line to give a simplified presentation of the data. The *x*-axis has a number of interesting features; for example, there is considerable variation in the time-periods over which the failures took place, with some villages starting and finishing their failure history over very different durations. This result reflects the early bore-holes which became salty, those that dried out and, more recently, the difficulty of finding any water at all in some of the outer villages. This measure of failure does not deal with the probability of failure at the time of drilling. It does, however, provide some insight into relative failure over time and any trends there may be which relate to this failure. It also offers some information on changes in aquifers, to the extent that failures in the overall data are dominated by bore-holes that are dry when drilled, or have become dry.

Table 4 Mean date (years) for the first planting of oranges and apricots (*n* refers to the number of respondents interviewed)

	Oranges			*Apricots*		
Zone No.	*Mean date (year)*	*SD*[1]	*n*	*Mean date (year)*	*SD*[1]	*n*
1	1969	10	12	1975	5	9
2	1961	13	26	1983	6	2
3	1965	9	29	1979	4	5
4	1973	9	5	-	-	-
5	1952	11	32	1982	-	1
6	1958	9	35	-	-	-
7	1969	14	14	1973	7	2
Combined	1961	12	153	1977	5	19

[1]SD = standard deviation (years)

AGRICULTURAL PRODUCTION AND WATER DEGRADATION

The examples that have been presented have been restricted to the qualitative and quantitative changes in irrigation water across the Argolid Plain. These have been represented in two ways: first, by the expansion through time of boreholes, thereby indicating the spread of irrigated agriculture; second, by the changes in depth to access water and the failure rates of those boreholes, indicating the spatial and temporal deterioration of the groundwater. These examples are useful for showing that social enquiry techniques can provide us with valuable information about the nature and extent of physical change.

These data have provided a comprehensive overview of the dynamics within the natural system which has been combined with information about the production system and the decisions attached to that system in order to provide a dynamic model in which crop characteristics, hydrology, and the agricultural economy have been investigated, as sub-models, over a 30-year period (Allen *et al.*, 1994). The development of this framework has facilitated the exploration of a range of different policy instruments (i.e. affecting crop price support, water distribution and control) and the identification of some areas of the natural system that may benefit from further in-depth investigation (i.e. the salt retention properties of various soils under a range of irrigation regimes). Several examples which link the costs and income for different agricultural regimes to their respective water requirements can be used to exemplify the problem, and to highlight some of the more obvious policy issues and dilemmas. These examples are based upon data that have been converted to zone level (see Figure 1). Essentially these zones are divided between those that are peripheral to the plain and nearby hill land with a more varied agriculture and problems with diminishing water stocks (zones 1, 3, 4 and 7), and the central area (zones 2, 5 and 6) with more mono-cropping and qualitative water problems, but with access to the canal infrastructure.

It is possible to link the current spatial distribution of irrigated agricultural production to its temporal emergence by considering the approximate dates on which specific irrigated crops were planted across the area. Table 4 shows this distribution for oranges and apricots, the main citrus and non-citrus irrigated crops. Despite the patchy nature of the data, particularly for apricots, Table 4 shows the spatial emergence of the crops and a clear distinction between the timing for the introduction of oranges and that for apricots. This information refers to the main crops grown by the farmers interviewed; no equivalent data were collected for other crops that they grew.

The apricot crop tends to have been introduced on the western side of the valley approximately 10–15 years after oranges were planted in the same zones. The apricot crop requires more local

Table 5 Proportion of irrigated land in study zones

Zone No.	*Mean* (%)	*SD*[1]	*n*
1	70.1	21	24
2	78.9	26	29
3	58.4	26	36
4	58.8	30	6
5	83.8	22	33
6	92.0	18	36
7	45.6	30	19
Combined	73.0	28	183

[1]SD = standard deviation

Table 6 Water requirements of crops in the study zones. Figures are $\times$ 10^3 m^3 ha^{-1} year^{-1}

Zone No.	*Fruit*	*Vegetables*	*Total*[1]
1	8 620	2615	11 236
2	1948	10 225	29 709
3	10 912	3960	14 872
4	5355	2732	8088
5	31 680	3260	34 940
6	25 502	12 335	37 837
7	8670	646	9317
Combined	110 225	35 776	146 001

[1]Water consumption is based upon estimates of 11 000 per stremma for fruit and 22 000 m^3 ha^{-1} for vegetables (10 stremmata ≈ 1ha)

labour both for production and for marketing, and is not so conducive to part-time farming. Such factors are significant when considering the way that agriculture has emerged in the past and, more importantly, as determinants of future change, particularly in the central plain. There is also a noticeable trend in the data of introduction of oranges away from the central valley to the periphery of the area (1952 and 1958 for zones 5 and 6 through to 1969 and 1973 for zones 4 and 7).

Table 5 shows the spatial distribution of irrigated land, with the central zones having a far higher proportion (> 90% in the case of zone six). This distribution is reflected in the water requirements for each zone, which are based upon the amount of irrigated crops already under production (Table 6). It is important to bear in mind that the groundwater in zones 5 and 6 is also heavily salinated and that most of the irrigation water is obtained from the canal infrastructure. These areas also suffer from acute frost problems, with a considerable amount of additional water used for crop protection.

Using these data, it is possible to estimate the relative cost of water by zone as a percentage of agricultural income (Table 7). This relative cost is based upon the total income, and the water cost, per stremma (where there are approximately 10 stremmata to 1 hectare). These figures have been obtained from the current prices for each crop received by the farmer and the production levels for each zone, based on official statistics. The cost of water was derived from the information about bought water and bore-hole costs (electricity and drilling) obtained from the interviews with farmers. The calculation is based upon the main crops grown by each of the farmers interviewed and so is primarily related to irrigated crops.

Table 7 shows clearly the differential cost of irrigated farming throughout the area, with zones 3, 4 and 7 having a considerably higher water-cost : income ratio than the central zones. Two explanations can be put forward for this. First, the farmers of the central zones have access to the canal infrastructure and so do not continuously drill deeper for ever diminishing water resources, with the accompanying costs. Second, the production per unit of land tends to be lower in the peripheral than the central zones (due to poorer soil, slope, etc.), and this is compounded by problems of water depletion. Two important points arise from this. First, the dependence upon citrus production within the central zones is reinforced by the existence of multiple job holding. As a result, a higher proportion of the farming population is unable to invest additional time to that which is required for the production of citrus fruits. Similarly, they are less likely to have the time, or the inclination, to sell their produce at local markets, albeit for higher prices than could be achieved through the supported price system. This is one element that helps to differentiate between types of farming in the region, and it also exemplifies an inequity, whereby some farmers from the central zones are able to accept decreasing prices. They can compensate for lower prices by the higher production per stremma and the existence of

Table 7 Variation in water-cost : income ratios between study zones (costs in drachmas)

Zone No.	*Income (per stremma)*	*Cost (per stremma)*	*Income : cost ratio (%)*
1	66 613	6777	10
2	86 266	5112	6
3	43 231	10 244	24
4	38 709	17 589	45
5	66 515	5716	8
6	77 398	4664	6
7	35 706	9890	27

other incomes. This is not the case with many full-time farmers, working lower-quality land on the periphery of the plain.

CONCLUSIONS

In this paper, examples have been given of temporal and spatial data about physical and technological phenomena that have been gained through interaction with the farming community. Such data must be seen as complementary to scientific and engineering analysis. In real situations, which are complex and messy, it is not possible for a single line of enquiry only to provide the richness and diversity of information required. What is required to complement detailed investigation is information suited to strategic analysis. The links between these two approaches – a hydrological model based on long-term measurement and research, and a complex systems model at a strategic level in which the hydrological and soil systems are just one of the interacting sub-systems – are themselves interesting, and have been expanded elsewhere (Allen *et al.*, 1994). Information derived from farmers cannot substitute for scientific investigation; rather there is a need for an iterative and complementary relationship between the two investigative approaches.

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THE COEVOLUTION OF SOCIETY AND TECHNOLOGY: UNDERSTANDING THE DYNAMICS OF COMMUNITIES AND UTILITY INFRASTRUCTURES

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Abstract - The ability of our societies to adapt in a sustainable way depends, in part, upon the coevolution of communities with those utilities which deliver fundamentally important services and products such as water, waste disposal, energy, telecommunications and transport. This paper seeks to contribute to such an understanding by advancing current thinking on the design of technological infrastructures. The focal theme of the paper is an examination of the contribution of novel 'small footprint' technologies in promoting the flexibility of utility supply systems. Some background to the theory of adaptive technology infrastructures is provided with references to case study material from the history and evolution of utility supply networks. Several specific 'small footprint' technologies with applications in the water, electricity and other fields are then discussed and their role within an adaptive technological infrastructure explained. Finally, we report the emergence of new tools for the design of adaptive technological infrastructures.

I. INTRODUCTION

Communities and their associated technologies can be seen as complex systems which evolve over time [1]. Research into the dynamics which underlie such evolution has characterised economic and social systems as the compound result of different activities that to some extent fit together and need each-other; a process of coevolution which is typical of many complex systems. The spatial organisation which is observed in these models emerges as a result of the interplay between positive and negative feedbacks. Examples of positive feedbacks include the urban multiplier effect, economies of scale and the influence of externalities. The dominant negative effect is spatial competition for both production and residential space.

As an example of this coevolutionary process we might consider the case of cities. The ability of a city's buildings and districts to physically co-evolve with changes in the demand for various services in part depends on decisions made about utilities and their infrastructures. One of the constraints on the design of buildings that can adapt over time to different uses is the current nature of utility systems technologies and the logistical properties they have. Historically, design assumptions about utility technologies have been about the need for large processing or production plants and elaborate fixed structure distribution systems. These were appropriate historically when the range of technologies was limited and spatial patterns of urban activity were assumed to be relatively static (although in practice in Victorian Britain not only was there rapid urban growth but the nature of use of existing locations was also changing rapidly). Decisions about such physically massive infrastructure at one point in time may lock buildings into design configurations inappropriate for future potential uses. Indeed it may be argued that utility systems have inhibited healthy urban evolution since the timescale for economic replacement of traditional process, production and distribution utility technologies is often decades longer than the timescale of potential changes in location and level of demand for their output. As we come to the time when large scale urban renewal and extensive new developments may have to be made it is timely to reconsider the potential role of utility technologies.

In the assessment of sustainable utility technology (such as water, gas, electricity etc.) which have traditionally been oriented around long lived physical infrastructures, Jeffrey distinguishes between flexibility - the options that are held open for the future, and adaptability - the ease or difficulty with which those options can be taken up when needed [2].

In terms of our example of the city, while it may be feasible to design buildings and groups of buildings which are flexible with respect to use, the constraints of the established utility infrastructures often means that this flexibility can only be consumed with considerable expenditure or a long time into the future when utility infrastructure and plant is due for replacement; in other words adaptability is, in practical terms, low.

However, coevolution is, by its very nature, a multi-dimensional process and the flexibility / adaptability of buildings is only one aspect of the problem. Scientists and engineers also need to develop technologies and bundles of complimentary technologies which exhibit adaptive capacity. Many contemporary process technologies (e.g. grey water recycling, hydrogen fuel cells, small gas turbine CHP etc.) exhibit such properties due to their small scale, enabling them to be both spatially distributed and used as part of a modular system (e.g. several linked but identical units to meet design capacity rather than one large unit). Many of these technologies also have inherent or designed environmental advantages over traditional technologies.

In broad terms, the ability of our societies to adapt in a sustainable way depends, in part, upon the coevolution of communities with those utilities which deliver fundamentally important services and products such as water, waste disposal, energy, telecommunications and transport. The spatial dynamics of an adaptive, sustainable community would be likely to give rise to substantial changes over time in the patterns and nature of utility demand (consumption 'footprints'). Indeed, changes in technologies, social priorities, spatial and temporal demand and supply patterns may, in time, necessitate major modifications to the configuration and operation of the system. The central issue of concern here is that technological systems for utility provision which are inflexible, are a source of coevolutionary friction. Such systems lock the communities which they seek to serve into infrastructures and technology configurations that resist adaptation. The temporal disparities which occur as systems try to adjust to meet new patterns of demand result in communities being badly served by inappropriately configured technology sets. The costs accrued (both in terms of absolute magnitude and temporal distribution) as a result of these mismatches are considerable, being historically labelled as processes of 'restructuring' or 'regeneration'. How can we design technology systems which support sustainable communities ? The concept of technological systems which can provide sustainable resource provision is closely associated with issues of service resilience through system flexibility and adaptivity which we now discuss.

II. RESILIENCE AND ITS INTERPRETATION IN TERMS OF TECHNOLOGICAL SYSTEMS

Resilience indicates durability or continuity. Its achievement is promoted by enhancing both the potential for change (flexibility), and the ability to change (adaptivity) in the system's plans, configurations and functions. In more detail, flexibility indicates a potential for change or the existence of alternative positions / strategies / configurations. In evolutionary terms, such a potential for change is defined by the totality of an organism's behaviour and its physical characteristics. The concept of flexibility has received wide attention in both the social and natural sciences. For example, the field of management science has provided a useful interpretation of flexibility, viewing it as '*the number of future alternatives from which a choice may be made*' [3]. Flexibility is promoted by two additional phenomena; diversity and learning.

Diversity is a central concept in evolutionary theory. A useful interpretation of diversity is provided by Pielou who comments that '*diversity bears to qualitative observations the relationship that variance bears to quantitative measures*' [4]. As a concept, diversity is readily transferred from biological to other systems. In its elementary sense, diversity alludes to the number and relative proportions of different typological groups in a community. Flexibility is also promoted by learning; the process of gaining knowledge or skill. Learning about your environment enables you to adapt your behaviour to exploit opportunities and avoid dangers.

Adaptation has been described as a process as the '*modification of structure or behaviour* [5]. Organisms adapt to their environments because in order to survive and reproduce, they must meet their environment's conditions for existence. If flexibility is the potential for change, then adaptivity is the ability to execute or exploit such change. Hence, a system may be flexible (have options for alternative action), but not adaptive (be able to utilise these options). Although most discussions of adaptation are couched in the terminology of the biological and ecological sciences, the field of General Systems Theory has been prominent in interpreting the key concepts for use (by analogy) in planning and modelling activities. For example, Shakun characterises an adaptive system as one that '*reacts or responds to change to attain goals*' [6]. Such change may be internal or external and the response type may be passive (changing itself) or active (changing the environment).

Translating the concepts discussed above to the subject area of technological systems, we can readily identify analogous processes and structures. A resilient technological system will possess both options for alternative modes of operation (flexibility), and the ability to exploit these alternatives (adaptivity). The central components of resiliency in technological terms might include; modular technology design, diversity of technology configurations, diversity of technology types, scale independent technology designs, and adaptive infrastructures.

For example, technology design can enhance the resilience of the system by ensuring that options for future action are not restricted by current attributes. In addition there will be a series of more qualitative features of the technology which may be dictated by considerations of resilience from a different perspective (i.e. environmental, economic etc.). The type of design considerations which will enhance resilience may include the use of a modular design approach which would enable the potential for re-utilisation of components in other system types either during the proposed life-cycle of the plant or post decommissioning. Generally, this ensures that the life-cycles of specific items of plant and their constituent elements are not necessarily identical, thereby engendering an element of modularity. Scale considerations are also an important factor in determining the resilience of a technological system and is closely linked to the network aspects discussed below. It is erroneous to assume that by scale issues is meant a preference for small scale applications. The relevant issue is rather concerned with appropriate scale dependent upon technology type and other factors. Life-cycle considerations can also influence the resilience of a system as the interactions between different component, sub system and system life-cycles creates opportunities for change and adaptation. Table 1 shows some key sources of diversity for electricity generation systems, together with those sources of environmental turbulence which they provide resilience against.

Table 1 Relationships between sources of diversity and variable factors.

Source of Diversity	Enabling resilience in the face of
Fuel source	Fuel costs / availability
Plant location	Demand pattern variability
Design life of plant	Technology changes
Output quality	Demand characteristics
Plant scale	Demand pattern variability
Lead time for construction	Changes in construction costs
Energy conversion process	Technology changes

The design of network characteristics will also have a significant effect on the resilience of a technological system. Both spatial and structural aspects are important here, resilience being resultant from the potential for additive or distributive flexibility. Similarly, investment strategies can exert a major influence on resilience as project timing, size, and level of commitment determine a measure of exposure, both financially and organisationally (resources etc.). Diversity of project attributes is a key feature of an investment strategy focused on resilience, allowing risk to be spread and learning processes to be engaged in without over-commitment.

In concluding this discussion of the characteristics of resilient technological infrastructures, we would identify two additional issues which require attention. Firstly, it should be noted that the concepts that have been reflected on in this and the foregoing sections are concerned with the attributes of the system under study rather than states of the system. This is a non-trivial distinction which is worth some further discussion. The difference between these two phenomena has particular relevance within the context of planning methodologies, where a focus on system states has been allied with a mechanistic approach to problem solving whereas a focus on system attributes has been associated with an evolutionary approach. The significance of this distinction in terms of technologies and technological systems has however not been widely addressed in the literature. The intended distinction here is that states are measures of specific system performance parameters whereas attributes are general qualities of system or sub-system behaviour. The distinction thereby emphasises the difference between quantitative and qualitative assessments of system performance. As an example, we may take the case of electricity supply systems where a state focused analysis would concentrate on issues of cost (capital and operating), efficiency (conversion and transmission), and return on investment. Conversely, an attribute focused analysis may look at system diversity, flexibility and adaptivity.

The second issue which requires some attention when thinking about resilient technological infrastructures concerns the nature of the relationships between various attributes. In particular, the hierarchical structure of the relationships between various attributes dictates their influence on overall system performance. For example, any utility in the form of flexibility that can be gained from the attribute of diversity is dictated by a dependence relationship between different hierarchical levels where diversity at a lower level promotes utility at a higher level. To illustrate this point consider the case of manufacturing technologies. Diversity of production technologies (each one held by a different firm) does not promote flexibility at the level of the firm but at the level of the sector. Likewise, the benefit of a diversified set of electricity generating technologies (each owned by a separate operator) is not of benefit to the operators of individual technologies but to the customers of the industry as a whole. Generically, diversity of individual behaviour does not further the interests of the individual but of the group.

III. THE DESIGN OF ADAPTIVE TECHNOLOGICAL SYSTEMS: ELECTRICITY GENERATION

We now move on to report the results of a study which demonstrates a form of technology analysis which focuses on system attributes and which can be used to investigate the systemic properties of technological infrastructures in terms of their resilience. Specifically, the study involves use of a computer based simulation modelling activity designed to assess the contribution of diversity to system resilience.

A central advantage of resilient, adaptive systems is their ability to cushion the shock of change (minimising coevolutionary friction). An adaptive system is able to maintain consistency in its functional performance whilst reconfiguring its internal structures and processes. Although good or utility provision is perhaps the most obvious function that should be maintained, an equally significant role is the maintenance of cost stability. Cost instabilities, particularly in the provision of what are often termed 'primary goods' (water, electricity, gas etc.), contribute towards both personal and national economic hardship. Hence, the focus of attention for the model described below is on the maintenance of cost stability in a utility-type technological infrastructure

The model is designed to investigate the comparative cost performance of two technology infrastructure design strategies; one of which utilises a single (initially cheapest) technology, and the second of which adopts a diversified technology base. The model is initialised with a 'current' technology set for each strategy which can be varied in number, size and age to reflect a particular technological system configuration at year 0. Scale, design life, and other technological characteristics of each individual item of plant can be set, providing the potential for investigations of technology configurations and design parameter issues. The model thereby begins each simulation with an operating plant set that already possesses a history of operation. Bounded, dynamic cost functions for each technology type are generated by a restricted random number algorithm. These auto correlated time series represent the capital, operating, dormancy, and maintenance cost profiles. Similar (though less flexible) examples of this type of model can be found in Law & Kelton [7]. A demand function for the notional industry is also generated within the same algorithm. The criteria which govern plant operation and investment in new or replacement plant are dictated in a separate sub-program, allowing a variety of investment and operating strategies to be assessed under differing operating environments. The actions of each of the two strategies (single technology and multiple technology) are then simulated at yearly intervals with plant investment and operating decisions reflecting current costs and technological characteristics.

It should be noted that the labels 'single technology' and 'multiple technology' do not refer to the number of items of plant but to technology types. Each strategy is able to access multiple units of plant of each technology type. The technology types themselves are analogous to technologies using different input factors to generate a single product or service. As the model simulates the operation of the industry, plant operation is managed by the operations sub-routine which sorts the set of available technologies into an operating order, dictated by age and operating cost criteria. Consecutive units of plant are then activated in sequence until demand is satisfied. All other built units attract a penalty cost for being maintained available but dormant. A survey of each plant set is then carried out to ascertain the need for replacement plant or new capacity to meet expected demand. Finally, yearly and cumulative costs accrued by each strategy are calculated and compared with a range of other cost and technology attribute variables to represent the configuration of the whole system.

Of the several tasks which the model is capable of fulfilling, the one selected for demonstration here involves an investigation of the benefits of an investment strategy focused on diversity of technological attributes (represented by the possession of more than one technology type). The desirability of promoting stability and consistency as characteristics of technological infrastructures was discussed above. The output parameters to be measured constitute the yearly costs accrued by both a multiple technology strategy and a single technology strategy operating under identical input cost conditions. For the purposes of these simulations, data relating to technology design and performance characteristics were obtained for a range of electricity generation technologies currently used by the U.K. electricity supply industry. Fig. 1 illustrates the total supply cost trends for each strategy and Fig. 2 shows the cumulative cost trends for each strategy.

These results clearly show the higher frequency of construction events for the strategy of diversity. When the cost trends for the two strategies are compared, the diversified strategy's yearly costs have less stability with regard to the number of fluctuations, but the variability is of a lower magnitude than those for the Single Technology Strategy. The cumulative cost trend (Figure 2) confirms the relative levels of output cost variability; the diversified strategy exhibiting a less variable trend. It should also be noted that despite the differences in yearly cost accrual, the final total cumulative cost for each strategy is very similar. These results raise an interesting point regarding the nature of turbulence. A turbulent cost trend may be acceptable if the nature of the turbulence is regular or understood. Furthermore, the magnitude of turbulence (in this case by how much the costs differ year on year), is as important a strategic issue as the frequency of change events or the type of turbulence encountered. form.

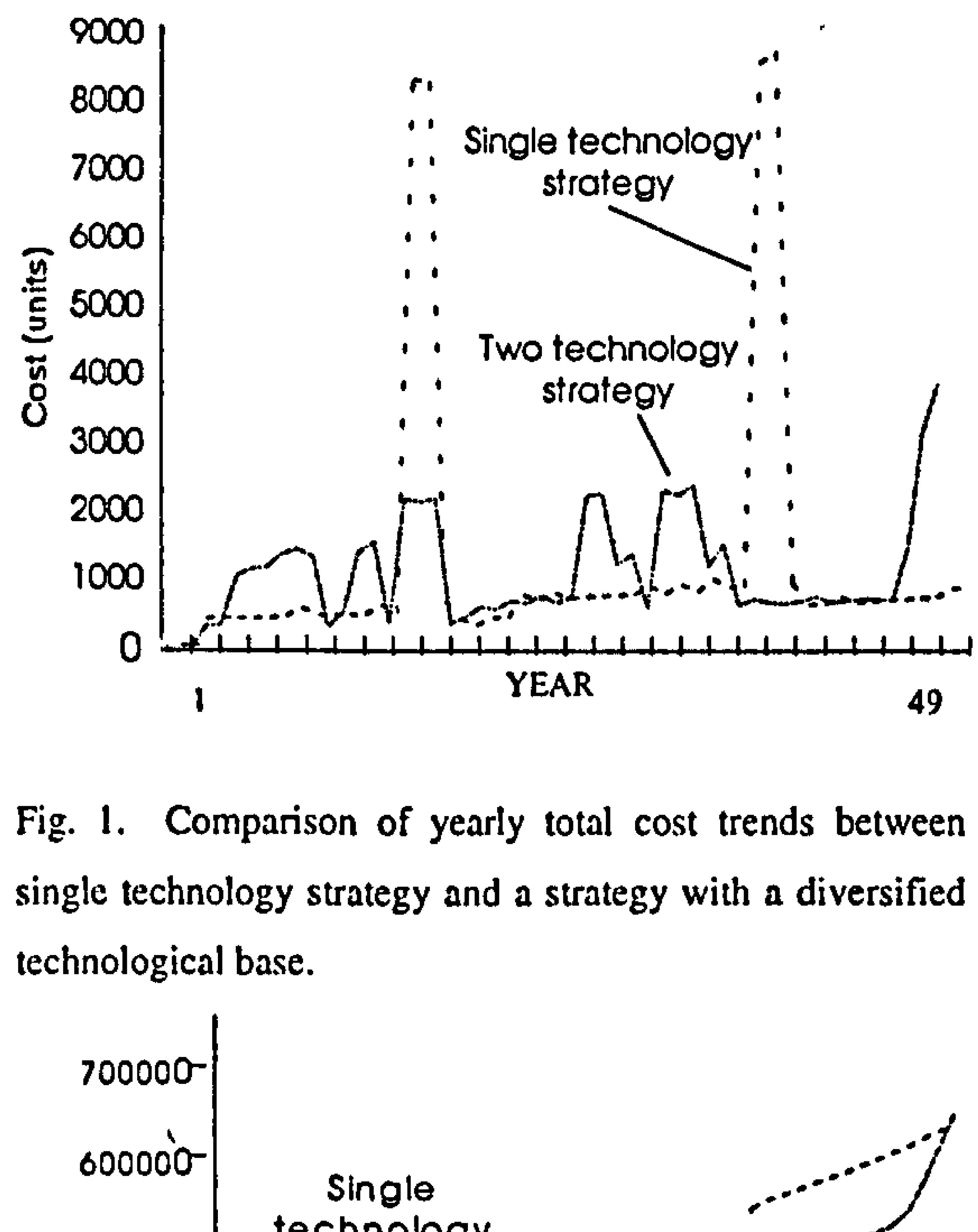

Fig. 1. Comparison of yearly total cost trends between single technology strategy and a strategy with a diversified technological base.

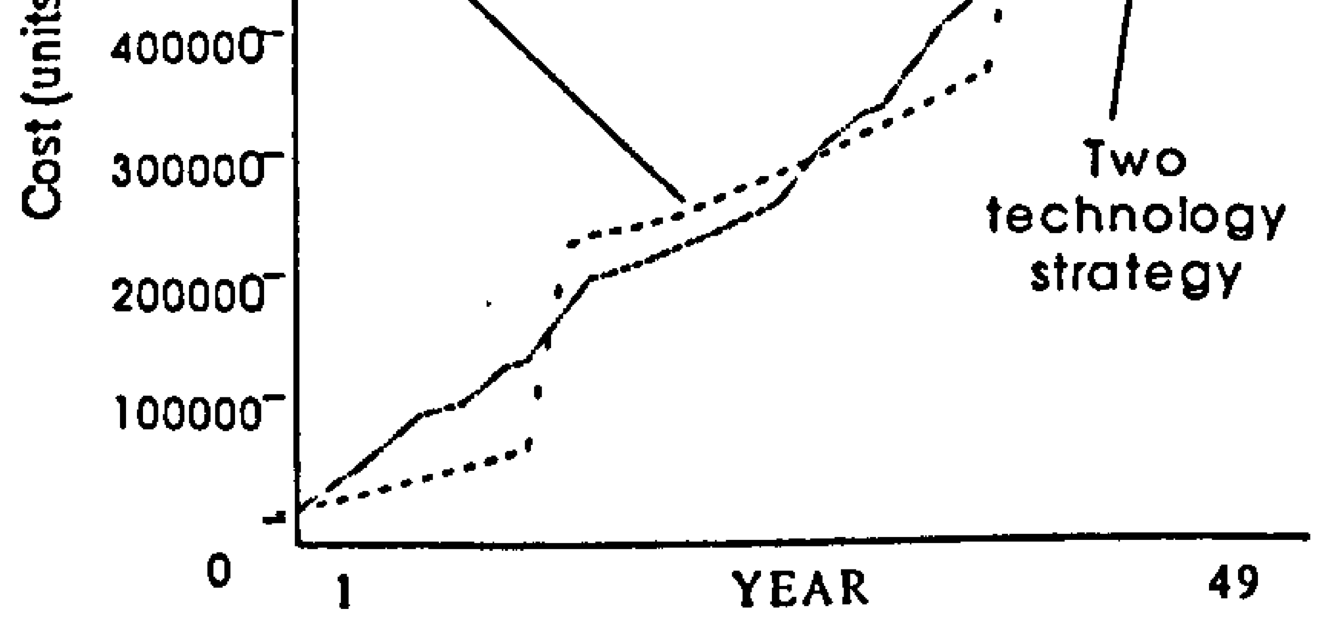

Fig. 2 Comparison of cumulative total cost trends between single technology strategy and a strategy with a diversified technological base.

From a policy perspective, the identification of these types of technological characteristics such sensitivities is of importance in relation to system design. If generic (technology independent) sensitivities can be isolated, then technologies could be specifically designed for operation in an adaptive, resilient technology base. The discussion presented below on the relative importance of systemic properties over individual plant attributes is also pertinent to this issue. Given an altered focus for analysing technological attributes, technology design could be guided by system level concerns rather than individual plant attributes, thereby enhancing overall system performance. Referring to the results of the modelling activity reported above for an example, technologies could be designed to lower the cost and increase the speed of substitution, two parameters which were found to have a significant influence on the cost performance of a diversified system. The simulation results also suggest that the operating environment itself should form as important an element of analysis as does the organisation and its constituent parts (technologies, organisational structure, human resources, finance etc.). Strategies based on technology diversity may not be well suited to relatively stable operating environments. The model results suggest that for a diversification strategy to be effective from a cost perspective, opportunities must arise (and arise frequently), for technology substitution. This may not necessarily occur through cost profile turbulence, and other technological attributes such as maintenance schedules and reliability issues may have an important effect on the efficacy of diversification.

Just as some parameters cause major changes in the utility of a strategy focused on technology diversity, so a number of factors can be identified from the model which have little effect on the overall benefit / disbenefit of a diversified technology base. These factors include plant age (as represented through decreased efficiency), lead time to build, and plant scale. Although these parameters were initially considered significant (as suggested by several published sources), their influence becomes relatively unimportant within a system which relies for its overall cost performance on the interplay between two or more sets of operating costs. This finding raises an important issue concerning the relative effects of individual plant and system effects on total cost trends and cost stability. Within a diversified technology system such as that modelled, system characteristics rather than individual plant attributes appear to be influential in determining system cost profiles. It is the interplay between various aspects of the system (as discussed above in relation to the sensitivity of benefits to key parameter changes) which dictates the cost performance of a diversified technology base.

There are a number of policy and methodological issues emergent from these findings. In relation to policy formulation, the need for a systemic (multiple unit / multiple influences) analysis of cost performance may broaden the scope of technology planning to include wider aspects of the problem such as complementary technology design (see previous section). A particularly interesting aspect of this element of the modelling results shows that the two parameters of lead time to build and plant scale become of marginal cost importance within a diversified system. The explanation for this lies in the type of diversity represented. Holding redundant capacity allows new plant to be constructed without the need for hard and fast completion dates. As long as there is enough capacity to meet demand, new plant can be constructed at an even-tempered pace. Similarly, diversity and redundant capacity in combination dictates low individual plant capacities in relation to total demand.

IV. THE DESIGN OF ADAPTIVE TECHNOLOGICAL SYSTEMS: WATER RECYCLING

Sustainable communities will require water supply systems which are capable of adapting to temporal and spatial variations in the demand profile. By viewing the co-evolutionary relationship between demand and supply in these terms, the criteria for desirable infrastructure characteristics are subtly altered. In particular, the system will be required to exhibit flexibility and adaptivity in the face of changing demand patterns. These characteristics can be enhanced by the use of novel water processing / recycling plant which provide opportunities for adaptive infrastructure configurations.

It would be easy to be critical of the water supply industry for failing to provide our communities with technologies and infrastructures that are not better capable of supporting changing economic and social patterns. However (and as has been the case with the other utility industries), imposed institutional, legal and financial frameworks have favoured a specific sub-set of available technologies and configurations. These *statutory functions* [8] effectively constrained the development of appropriate physical systems and suppressed the realisation of potentially useful intellectual contributions from the Water Science community. With the removal of these strictures and increased awareness concerning the dangers of adopting an indifferent attitude to infrastructure design, new opportunities arise for the planning of systems which truly contribute to the sustainability of our communities. By exploiting the attributes of novel wastewater recycling technologies within an infrastructure design philosophy that reflects an understanding of issues such as co-evolution and adaptivity, such opportunities can be exploited to the full.

A central feature of much recent research into water recycling / reuse technologies has been the focus on small scale applications. Perhaps the leading source for such applications is Japan where there is a well developed research programme into in-building wastewater treatment and water recycling processes [9]. However, rising demand profiles and increasing incidences of water shortages in many parts of the world have prompted wider interest in the sorts of technologies which provide opportunities for designing resilient (adaptive) water supply / recycling systems.

For example, the use of household scale sandfilters and physical filter / membrane systems for recycling domestic bath / shower water have been proposed [10]. Perhaps of even greater relevance are those process treatment technologies based on the use of membranes. Of particular significance, advances in recycling systems based on biological aerated filter (BAF), molecular oxygen-dosed membrane bioreactor (MOD-MBR) and ultrafiltration (UF) based membrane bioreactor techniques have been reported and are currently under test in both the UK and elsewhere. Similarly, there are opportunities for exploiting the performance attributes of technologies which have reduced chemical requirements. These 'small footprint' technologies extend the opportunity space for the design of water supply infrastructures by providing greater flexibility with regard to technology scale, siting and functionality [11]. This flexibility is also reflected in the logistical and economic properties of the system. Hence, the capacity of these types of technologies to recycle grey and black water at the neighbourhood, street or even household level exposes new opportunities for the design of water supply / sewerage networks. The potential exploitation of such technologies as part of a resilient utility supply system has largely been neglected by researchers and industry alike. The cost efficiencies of large scale plant have dominated technology design frameworks to the detriment of other considerations. An example from the water industry demonstrates how an alternative approach can expose the utility of a technology in terms of appropriate rather than absolute levels of effectiveness.

Membrane Bioreators (MBRs) are gray-water treatment units which combine membrane technology with biological reactors for the treatment of municipal and industrial wastewaters. The maintenance of high cross-flow velocities and membrane permeability requires high energy input to the process. The specific energy consumption of the plant depends on the membrane area, the cross-flow velocity in the membrane module and the oxygen requirements of the microorganisms. Additionally, power requirements will increase over time as membrane permeability decreases.

An analysis of MBRs in terms of their potential contribution to an adaptive utility supply system was undertaken with specific emphasis on the effect of scale on the plant's operating parameters. Fig. 3 depicts the

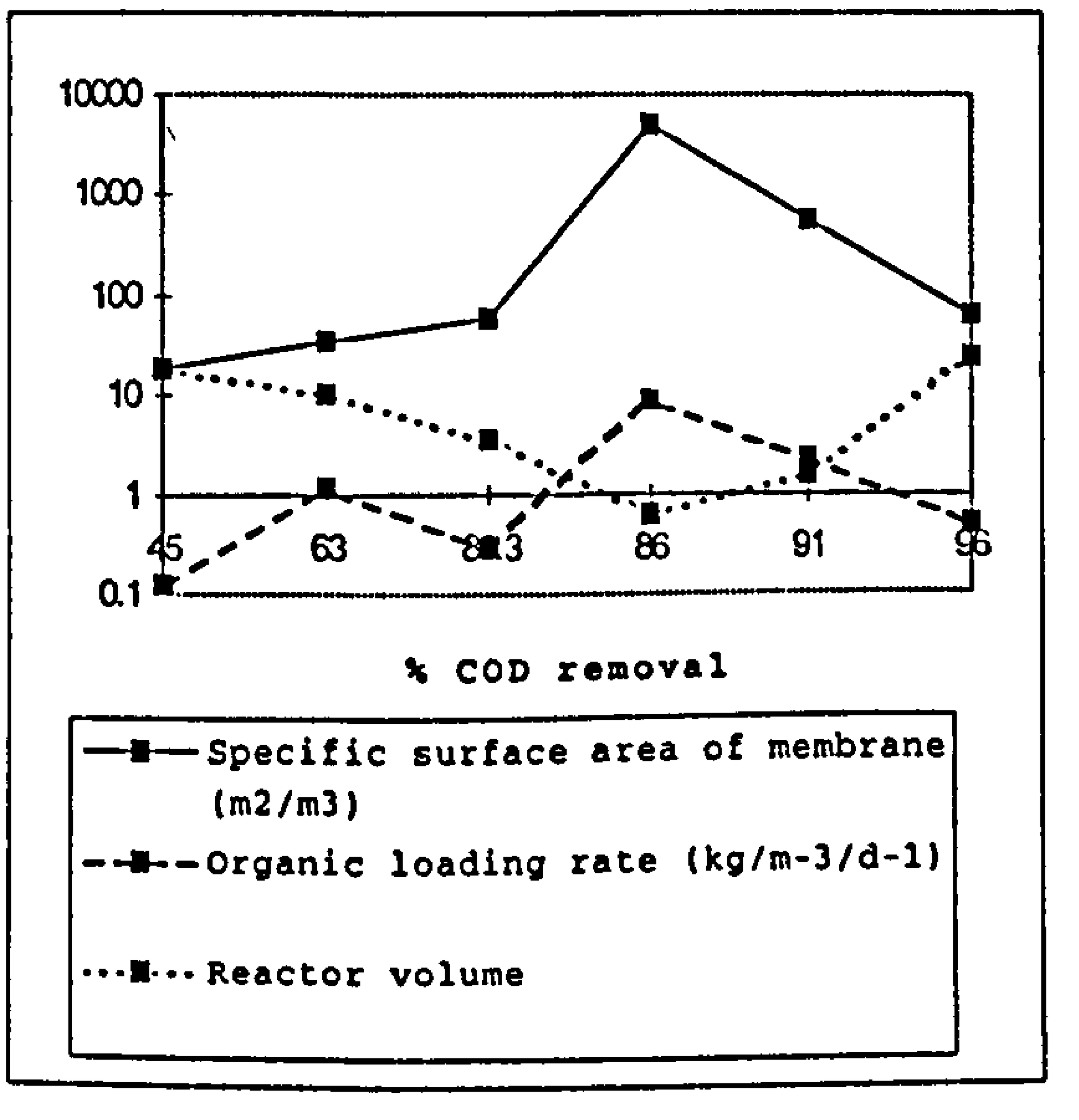

Fig. 3. Effect of scale variables on plant effectiveness for a Membrane Biological Reactor

relationship between a performance variable (COD removal) and three key scale / configuration design variables (specific surface area, organic loading rate and reactor volume). These last three variables can be seen as proxy measures of cost whilst the first gives an indication of objective function performance. If the only criteria for selecting an appropriate scale for the technology was objective function performance, then there is a clear optimum scale for plant design. However, if we consider the relationship between the three cost variables (reactor volume, specific surface area and loading rate), we can identify an alternative appropriate scale where reactor volume is at a minimum. The level of COD removal is clearly reduced at the second point, but the water may still be sufficiently clean for use in non-potable applications.

MBRs are an example of a new generation of small footprint technologies that provide opportunities for the design of adaptive technology infrastructures, thereby limiting coevolutionary friction. Given a set of recycling technologies such as that described above, we can begin to see how an appropriate analysis methodology for designing a water supply / recycling infrastructure for an urban area might be constructed. The following issues will form the basis for such a methodology.

Flexibility: temporality and uncertainty: Issues about specific processing technology units can be explored through calculating the cost and performance envelopes of a set of technologies under conditions of uncertain input costs, demand levels and quality over sustained periods of time.

Adaptability: system configurations and cost / performance trade-offs: These issues can be addressed by considering water recycling technologies within the wider infrastuctural system of catchment, processing, delivery and disposal as part of an evolving logistical system and investigating how different technologies perform.

Scale, hierarchy and complexity: It is necessary to formally identify how the water system can be introduced as an interactive sub-system into wider urban system models. The way in which such water supply (and disposal) systems will consist of different technologies at different spatial scales (building, street, community, district, city) and hierarchies, all of which have some economic, physical and social dynamic, is part of a wider research agenda into sustainable cities as complex, dynamic and evolving systems.

It is particularly important for further work to be carried out on formalising the structure of these hierarchical elements and developing an appropriate language for describing their main features. For example, diversity, flexibility and adaptivity are reflected in different elements of a technology. Hence, models should be able to capture the pertinent sources of diversity etc. for each technology or group of technologies. Furthermore, effective, generalizable ways of analysing attributes rather than states need to be developed in order for a generic model type to be possible. It is not clear whether such a generic technology planning model based on issues of resilience is achievable and further research is needed to test the robustness of the concepts used.

Existing research has already demonstrated the principles of this approach but two main challenges now present themselves. The first is to work with actual engineering and economic data about real technologies and networks in order to show how such an approach can be operationalised. This requires collaboration between scientists, engineers and technology modellers. The second is to show how the notion of sustainability in water systems, which themselves are at the base of a hierarchy of urban systems, can be integrated with the notion of Sustainable Cities. This requires collaboration between urban and technology modellers. Finally, both of these challenges require a proper understanding and representation of the needs of people. Ultimately, societies are the sole reason for the construction of cities and the design / management of technologies. The matching of the diversity of water demand profiles (in terms of quality and quantity across time and space) with opportunities provided by novel recycling technologies is a central challenge for the development of sustainable water utilisation strategies.

V. CONCLUSIONS

The examples of technology design for resilient utility supply discussed above can be seen as two tactical approaches to the achievement of the same strategic aim. In the electricity supply example, redundant capacity was used as the source of diversity, providing the opportunity space for adaptive change. In the water recycling example, the source of adaptive capacity would be in terms of bundles of technologies which can be reconfigured to exploit emerging recycling opportunities. These are examples of the types of technology design and application concepts that are required if we are to reduce the coevolutionary friction generated by inflexible technology sets. Several specific studies (both completed and ongoing) have demonstrated the potential contribution of thinking about resilient technological systems in the terms discussed above. For example, the effect of a diversified technology base (multiple technology types exhibiting similar functions but varying scales and operating characteristics), on total system cost stability has been demonstrated by Jeffrey, who also made some broad conclusions regarding the generic benefits to be gained from such a technological configuration [12]. Further contributions, carried out as part of the European Community's Environment and Climate research programme have focused on the relationships between technological infrastructures and land use change [13]. This work has drawn attention to the need for designing water supply infrastructures that are capable of supporting social and economic changes rather than 'locking' communities into rigid spatial and temporal patterns [14].

What has been sketched out in this contribution is a first step in the recognition of coevolutionary processes and the phenomenon of coevolutionary friction. Science tells us what can be done in absolute and unconditional terms. Before we invite engineering to realise such potentials, we need to consider carefully what should be done. Infrastructures which are charged with primary good supply will continue to play a significant role in the development of sustainable economies and communities. Just how the desirable performance characteristics for such infrastructures are identified, instilled and managed constitutes a challenge for both the research and commercial communities.

By making various dimensions of resilience a significant if not the foremost criteria for system design, we are accentuating the connections between technology, economy and society. Unless technological systems are able to exhibit adaptivity, these connections will become strained, turning technology into the burden rather than the servant of our communities.

VI. ACKNOWLEDGEMENT

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SUSTAINABILITY AND SYSTEMS THINKING: THE COEVOLUTION OF COMMUNITIES AND TECHNOLOGICAL INFRASTRUCTURES.

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1. TECHNOLOGY AND SUSTAINABLE DEVELOPMENT

Unchecked technological development in general is at least partly responsible for some of the undesirable and survival threatening phenomena observed today. Problems of pollution, over-production, resource (and capital) concentration, restricted product lifecycles, and lack of social control, have all been attributed to 'technology'. However, whilst there is general consensus regarding the role of technology in creating the problem, there are diverse attitudes towards its future contribution (the debate between the various positions is extensively developed by Gillot and Kumar, 1995).

Two particular features of contributions on technological futures within the sustainable development literature which restrict the scope of debate. The first of these restrictions concerns the perceived nature of 'the problem'. Queries concerning the identification of a desirable and positive role for technology within sustainable societies has been dominated by issues of how much technology rather than what type of technology. The second restriction has been an emphasis on environmental issues, resulting in a prescriptive movement which espouses a 'greening' of the economy. It is the contention of this paper that a significant aspect of the contribution on certain types of utility technologies to sustainable societies' has been largely ignored.

Sustainability is promoted by adaptive change; a concept rarely, if ever, addressed in the literature on technological options for sustainable development. If technologies are to make a genuine contribution to the achievement of sustainable communities, the pertinent focus of attention should be on the design, operation, and management of adaptive technologies and technological systems. The planning of long term technological infrastructures concerns the development of planning methods and implementation strategies designed to ensure consistency in technological system performance over changing operating conditions. In particular, the design of resilient, adaptive technologies and technological systems will enhance the sustainability of our communities and economies under conditions of change.

Within the context of designing and managing sustainable communities, planners require an understanding of the interactions between the macroscopic dynamics of the regional or urban system and its component sub-systems. One major feature of this interaction is the way in which utilities' infrastructure and technology can be designed to allow for flexibility and adaptivity of urban built form as urban systems evolve under conditions of uncertainty.

2. RESILIENCE & TECHNOLOGICAL SYSTEMS - A 'SYSTEMIC' PERSPECTIVE.

Several bodies of literature engage in a debate about resilience and adaptivity, typical representative texts coming from Pielou (1975), Holland (1975), Pye (1978), Shakun (1981), and more recently, Jeffrey (1996). Translating the concepts of adaptivity. from their roots in evolutionary and systems theory into the subject area of technological systems, we can readily identify analogous processes and structures. A resilient technological system will possess both options for alternative modes of operation (flexibility), and the ability to exploit these alternatives (adaptivity). The central components of resiliency in technological terms might include; modular technology design, diversity of technology configurations, diversity of technology types, scale independent technology designs, and adaptive infrastructures.

Technology design can enhance the resilience of an utility system by ensuring that options for future action are not restricted by current attributes. In addition there will be a series of qualitative features of the technology which may be dictated by considerations of resilience from a different perspective (i.e. environmental, economic etc.). The type of design considerations which will enhance resilience may include the use of a modular design approach which would enable the potential for re-utilisation of components in other system types either during the proposed life-cycle of the plant or post decommissioning. Generally, this ensures that the life-cycles of specific items of plant and their constituent elements are not necessarily identical, thereby engendering an element of modularity. Scale considerations are also an important factor in determining the resilience of a technological system and are closely linked to network attributes. It is erroneous to assume that by scale issues is meant a preference for small scale applications. The relevant issue is rather the extent to which appropriate scale is dependent upon technology type and other factors. Life-cycle properties can also influence the resilience of a system as the interactions between different component, sub system and system life-cycles creates opportunities for change and adaptation. The design of network attributes will also have a significant effect on the resilience of a technological system, both spatially and structurally.

Two additional issues require attention. Firstly, it should be noted that the key concepts that have been reflected on in this and the foregoing sections are concerned with **attributes** (general qualities of system or sub-system behaviour) rather than **states** (measures of specific system performance parameters). This is worth some further discussion. The difference between these two phenomena has particular relevance within the context of planning methodologies, where a focus on system states has been allied with a mechanistic approach to problem solving, whereas a focus on system attributes has been associated with an evolutionary approach which is in turn more suitable for the study of emergent phenomena. For example, Allen argues that conventional approaches to modelling systems operate by identifying the components of the system and the interactions between them, and expressing these as a set of causal relationships, to give a mechanical representation of the system (Allen, 1995). However, the predictions generated by such a model can only be true as long as the qualitative structure of the system remains unchanged.

The second issue concerns the nature of the relationships between various attributes. In particular, the hierarchical structure of the relationships between various attributes dictates their influence on overall system performance. This point recognised by Checkland, who identifies 'emergence' as one of the fundamental ideas of systems thinking, stating that: *"It is the concept of organised complexity which became the subject matter of the new discipline 'systems'; and the general model of organised complexity is that there exists a hierarchy of levels of organisations, each more complex than the one below, a level being characterised by emergent properties which do not exist at the lower level"* (Checkland, 1981). For example, the benefit of a diversified set of electricity generating technologies (each owned by a separate operator) is not of benefit to the operators of individual technologies but to the customers of the industry as a whole. Generically, diversity of individual behaviour does not further the interests of the individual but of the group; ecologists would recognise this as the tension between individual species and community survival.

3. URBAN WATER SUPPLY INFRASTRUCTURES

A central feature of much recent research into water recycling / reuse technologies has been the focus on small scale applications. For example, the use of household scale sandfilters has been suggested (Glücklich, 1995), and physical filter / membrane systems for recycling domestic bath / shower water have also been proposed (Murrer and Bateman, 1996; Till et al, 1995). Of particular significance, advances in recycling systems based on biological aerated filter (BAF), molecular oxygen-dosed membrane bioreactor (MOD-MBR) and ultrafiltration (UF) based membrane bioreactor techniques have been reported (Pankhania et al, 1994) and are currently under test in both the UK and elsewhere.

The implications of these types of technologies for water supply and recycling networks are primarily to do with the development of evaluation methods Given a set of recycling technologies such as that described above, we can begin to see how an appropriate analysis methodology for designing a water supply / recycling infrastructure for an urban area might be constructed. The following issues will form the basis for such a methodology.

Flexibility: temporality and uncertainty: Issues about specific processing technology units can be explored through calculating the cost and performance envelopes of a set of technologies under conditions of uncertain input costs, demand levels and quality over sustained periods of time. In design terms, flexibility is promoted by providing a technology function and performance envelope which goes beyond immediate or anticipated needs. Individual technologies will typically exhibit modularity, long life-cycles, and resilient operating efficiencies over changing throughput volumes and qualities. The beneficial use (application) of such technologies in terms of providing support for a changing community is dependent upon the nature of the network within which they are embedded.

Adaptability: system configurations and cost / performance trade-offs: Exploiting a stock of flexible technologies involves providing a suitable infrastructure or network which translates flexibility into adaptivity. These issues can be addressed by considering water recycling technologies within the wider infrastuctural system of catchment, processing, delivery and disposal as part of an evolving logistical system and investigating how different technologies perform. The nature of the network in terms of its spatial arrangement, level of connectedness, directionality, functional potential, and capacity for expansion will not only determine its value as a source of adaptivity but will also set an agenda for technology design.

Scale, hierarchy and complexity: It is necessary to formally identify how the water system can be introduced as an interactive sub-system into wider urban system models. The way in which such water supply (and disposal) systems will consist of different technologies at different spatial scales (building, street, community, district, city) and hierarchies, all of which have some economic, physical and social dynamic, is part of a wider research agenda into sustainable cities as complex, dynamic and evolving systems.

The utility of wastewater recycling technologies in terms of their contribution to infrastructure resilience derives from their qualitative role in the network. The readiness with which they can be utilised at various scales of application (for example) is of equal, if not greater, significance as their cost effectiveness. The pertinent questions are concerned with issues such as technology type and location, rather than solely cost and performance.

4. COEVOLUTION OF TECHNOLOGY AND SOCIETY.

The ability of our societies to adapt in a sustainable way depends, in part, upon the coevolution of communities with those utilities which deliver fundamentally important services and products such as water, waste disposal, energy, telecommunications and transport. The development of models of communities as complex self organising systems shows that the spatial dynamics of a sustainable community would be likely to give rise to substantial changes over time in the patterns and nature of utility demand (consumption 'footprints'). Indeed, changes in technologies, social priorities, spatial and temporal demand and supply patterns may, in time, necessitate major modifications to the configuration and operation of the system. The concept of technological systems which can provide sustainable resource provision is closely associated with issues of technology flexibility, change, and socio-economic policy, and to associated issues of Demand Side Management (DSM) (Guy and Marvin, 1995).

The emphasis on attributes over states can be seen as the application of some key distinctions made by a number of prominent theorists. In particular, distinctions have been drawn between causal / mechanistic approaches to issue analysis and evolutionary approaches which allow for the existence of emergent properties. The roots of this distinction go back as far as John Stuart Mill, who, in considering the processes of causation and induction, also distinguishes between combinations of causes whose joint effect is the sum of their separate effects, and those where the combination of several causes leads to effects which are qualitatively different (Mill, 1904). To these ideas of causation and qualitative change, with their implicit time dimension, Morgan adds the concepts of hierarchy and process (Morgan ref ?). Morgan is concerned with the evolution of more complex structures from simpler ones. Although at each level, the components may be characterised as "things" which take part in "processes, he argues that what is "new" at each new level of the hierarchy is the ways in which the components of the previous level relate to each other. These observations suggest that the management of emergent phenomena has to be directed at a different level from that at which the effect is observed.

Any arbitrarily defined spatial zone (city, region, state etc.) can be seen as a complex system which evolves over time. Research into the dynamics which underlie such evolution has characterised city and regional economies as the compound result of different activities that to some extent fit together and need each-other; a process of coevolution which is typical of many complex systems. Information relating to the coupled development through time of communities and the technological infrastructures which sustain their most basic needs (food, shelter, warmth etc.), can be identified from a variety of disciplinary sources (e.g. History, Anthropology, Sociology, Engineering, Economics). However, interdisciplinary analyses focused on policy relevant output are now required to convert what is a disparate knowledge base into a focused, coherent understanding of socio-technical issues. Through such an agenda, the resultant understanding of the **coevolution** of society and technology, at the very least in terms of their spatial and temporal dependencies, will enhance our ability to plan (though not necessarily control) a sustainable future.

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