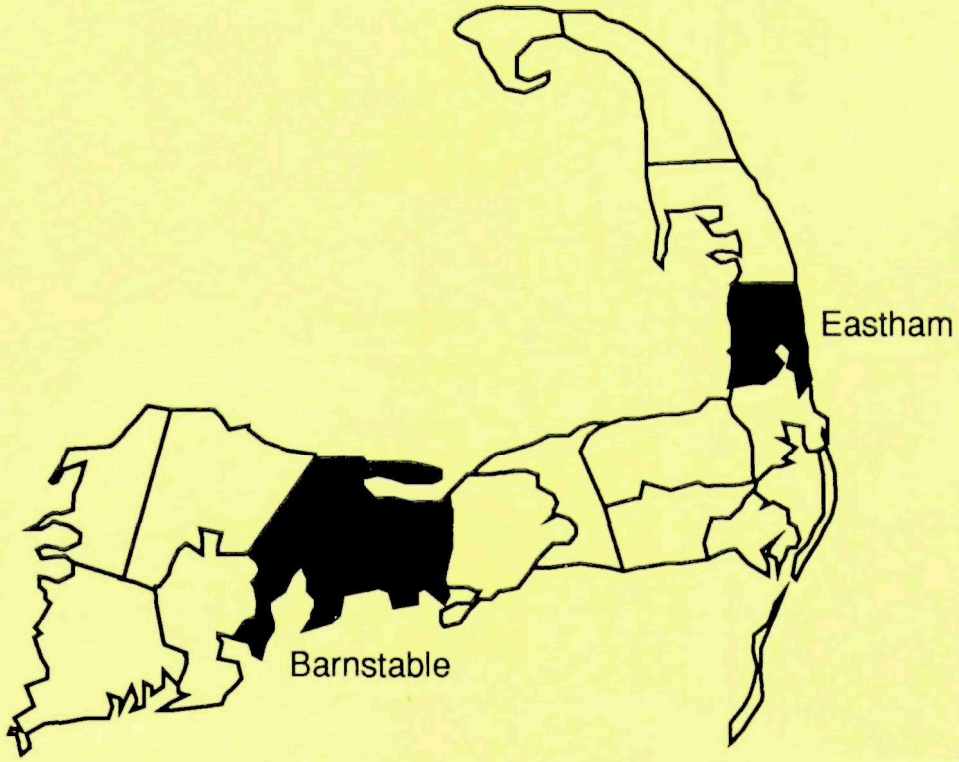
EPA 901/3-88-005

THE CAPE COD AQUIFER
MANAGEMENT PROJECT (CCAMP)

Demonstration of a Geographic Information System for Ground Water Protection



CCAMP WAS UNDERTAKEN BY:

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION I
U.S. GEOLOGICAL SURVEY, MASSACHUSETTS DISTRICT OFFICE
MASSACHUSETTS DEPT. OF ENVIRONMENTAL QUALITY ENGINEERING
CAPE COD PLANNING AND ECONOMIC DEVELOPMENT COMMISSION

IN COOPERATION WITH:

THE TOWN OF BARNSTABLE AND THE TOWN OF EASTHAM

SEPTEMBER 1988

THE CAPE COD AQUIFER
MANAGEMENT PROJECT (CCAMP)

Demonstration of a Geographic Information System for Ground Water Protection

Edited by

Lee Steppacher
USEPA, Region 1

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION I
U.S. GEOLOGICAL SURVEY, MASSACHUSETTS DISTRICT OFFICE
MASSACHUSETTS DEPT. OF ENVIRONMENTAL QUALITY ENGINEERING
CAPE COD PLANNING AND ECONOMIC DEVELOPMENT COMMISSION

SEPTEMBER 1988

The Cape Cod Aquifer Management Project (CCAMP) was a two year cooperative effort undertaken by the U.S. Environmental Protection Agency, Region I; the U.S. Geological Survey, Massachusetts District Office; the Massachusetts Department of Environmental Quality Engineering; and the Cape Cod Planning and Economic Development Commission in the towns of Barnstable and Eastham, Massachusetts. Its purpose was to investigate methods and approaches to be utilized in a comprehensive resource-based ground water protection program. Additional copies of this report and others published by CCAMP are available from the National Technical Information Service, Springfield, Virginia.

This document was published with funding made available through the Environmental Protection Agency's Office of Ground Water Protection and Office of Drinking Water. The contents may not necessarily reflect the policies or decisions of these two offices. The document solely reflects the views of CCAMP participants.

TABLE OF CONTENTS

Section	Title	Page
I.	PROJECT CONCEPTION	1
II.	PROJECT DESCRIPTION	4
	A. GIS Technology	4
	B. Project Objectives	4
	C. Organization	5
III.	DATA ACQUISITION	6
	A. Choosing Base Maps	6
	B. Data Sources and Automation	8
	C. Data and Map Verification	10
IV.	SCENARIOS	14
V.	LESSONS LEARNED -- RECOMMENDATIONS FOR FUTURE PROJECTS	25
VI.	ASSESSMENT AND CONCLUSIONS	31

LIST OF FIGURES

Number	Title	Page
1	Map of Cape Cod.	3
2	Maps Used in the GIS Project	7
3	Data Coverages	9
4	Class V Underground Injection Wells.	11
5	GIS Staff Requirements	12
6	Sixteen Proposed Scenarios	15
7	Outline of Scenarios Process	16
8	Screening for Potential Public Water-Supply Sites, Eastham, MA.	34
9	Screening for a Potential Stump Dump Site, Eastham, MA	35
10	Inter-town Management: Zoning and Landuse Across Barnstable and Yarmouth Town Boundaries (A).	36
11	Inter-town Management: Zoning and Landuse Across Barnstable and Yarmouth Town Boundaries (B).	37
12	Increase of Potential Risk to Public-Supply Wells from Landuse Build-Out, Barnstable, MA	38
13	Landuse-Based Calculation of the Average Nitrate Load to Ground Water Within the Zone of Contribution Barnstable, MA	39
14	Assessing Risk to Ground Water Quality at Public Water-Supply Sites from Underground Storage Tanks.	40
15	Assessing Risk to Ground Water Quality at Public Water-Supply Sites from Landfills.	41
16	Zones of Contribution and Half Mile Buffers Around Public Supply Wells.	42

DEMONSTRATION OF A GEOGRAPHIC INFORMATION SYSTEM FOR GROUND WATER PROTECTION

I. PROJECT CONCEPTION

A Geographic Information System (GIS) is a computerized graphic system with automated database management functions. This report summarizes the application of GIS technology to the Cape Cod Aquifer Management Project (CCAMP). This CCAMP's experience is described as are problems and resolutions in data acquisition, scenarios devised to demonstrate various aspects of the technology, and final recommendations and conclusions.

The Cape Cod Aquifer Management Project (CCAMP), was initiated by the U.S. Environmental Protection Agency, the U.S. Geological Survey (USGS), the Massachusetts Department of Environmental Quality Engineering (DEQE) and the Cape Cod Planning and Economic Development Commission (CCPEDC) to develop an integrated, resource-based approach to ground water management involving all levels of government. The project, conducted from 1986 to 1988, involved a detailed examination of the many threats to the ground water on Cape Cod and the development of improved scientific methods for protection of the resource from these threats. The institutional framework regulating these potential threats was evaluated and recommendations for stronger protection programs were made.

Much of the focus of concern in CCAMP was on accurately defining the resource to be managed, identifying the activities which threaten the integrity of the resource and thus need to be controlled, and developing the appropriate means to implement effectively any management scenario. One of the realizations stemming from this work was that although resource-based ground water management strategies have increased public awareness of the potential conflict between development and water resources protection, the threat to public water supplies from existing and future land use activities is still significant. Generally, regulatory programs are not designed to manage existing activities in proximity to public supply wells according to their threat to such wells. Although the information on which future land use decisions are made is voluminous, it is incomplete and the impacts of land use decisions on ground water are not easily predicted or easily displayed. There is an increasing need to evaluate available environmental data quickly and accurately to determine potential risks to public water supplies.

CCAMP found that risk assessment has seldom been performed by regulatory and planning agencies in a comprehensive way. Part of the problem in performing more sophisticated analyses is that the available data are often not organized or integrated in a useful way. Much of the available mapped data have been drafted manually at different scales and dates. Comparing different maps, or updating them, is a cumbersome process. Tabular data such as information on well characteristics, often lack good geographic location data. Data collection by various agencies on similar threatening activities

usually lacks common identifying features, such as identification numbers that would allow them to be cross referenced or aggregated.

Recent innovations in computerized data management offer improvements that could help overcome these problems. In particular, geographic information systems (GIS) technology provides efficient data handling, manipulation, and display capabilities that facilitate the analysis of large amounts of spatially referenced environmental data. It has the capability for overlaying various mapped data layers, determining distances from fixed points, automatic changing of map scales, and preparing maps from tabular point data. Its presentation is graphically clear, resulting in a more thorough understanding of the complex issues and consequently better decision making.

The agencies involved in CCAMP decided that it would be desirable to demonstrate the usefulness of GIS technology for these applications and to evaluate the problems which might arise in using it. Accordingly, GIS was used for a series of pilot analyses for Cape Cod. The work concentrated on the development of a digital database and assessment at three different geographic levels of analysis: 1) the zone of contribution to nine public water-supply wells in a highly urbanized area, 2) a rural, seasonally populated, summer tourist town, and 3) the Cape Cod peninsula. Figure 1 provides a map of the Cape Cod area. The project was designed to raise issues and answer the types of ground water management questions being asked on Cape Cod, but also those faced by ground water managers in other areas of the country as well.

CCAMP participants were especially interested in the ability of GIS to incorporate a resource-based approach into a comprehensive ground water analysis, that is, its capability to assess changes in risk associated with the protection of the most vulnerable ground water resource areas. CCAMP defined this area to be synonymous with zones of contribution (ZOC) to public water supply wells, defined as that area of land surrounding a pumped well under which water moves towards it and directly contributes to the water withdrawn. Within these ZOCs, any contamination from the land surface which travels through the soil to the water table and travels with the ground water will reach the well. Only in areas dependent on private wells are individual ZOCs not used to define the most vulnerable resource areas; instead the entire area is considered at risk. This demonstration project was successful in illustrating how GIS can improve the analyses required to implement a resource-based approach to ground water management.

One of the many applications of this technology in which CCAMP was particularly interested was the assessment of risk to water-supply wells from potential contamination sources. It is possible to rank the priority for clean up or to conduct a detailed assessment of various waste sources, such as hazardous waste sites or landfills, based on multiple environmental features. Site assessment studies to determine the most desirable locations for new resource uses (such as public supply well sites) or for new facilities with contamination potential are also greatly facilitated with this technology. These applications were also demonstrated as part of the project.

LOCATIONS OF AREAS OF STUDY

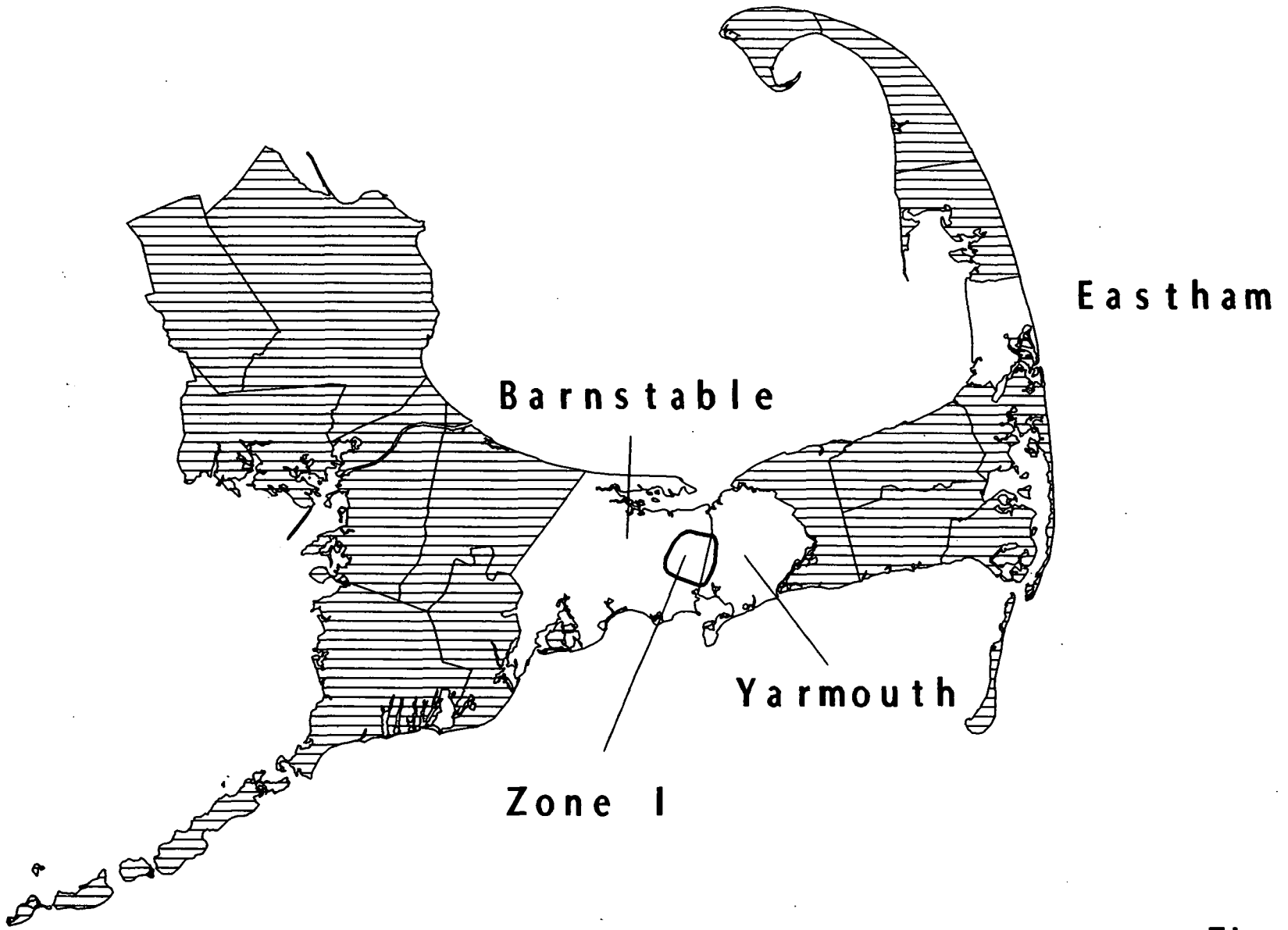


Figure 1

II. PROJECT DESCRIPTION

This section first briefly reviews the basic methodology of GIS. It then explains CCAMP's objectives with respect to the use of GIS technology. Finally, the organization of the team responsible for the GIS demonstration project is described.

A. GIS Technology

Geographic information system technology is unique in that it integrates computer graphic capabilities with an automated database management system. Historically, these computer functions and capabilities have existed independently; GIS brings together both tools.

GIS is designed to permit users to display data comprised of points, lines, and polygons which are fundamental to spatial relationships. It also allows descriptive data values attributed to the graphic information to be compiled and manipulated. It has the capability to apply a wide range of analytic techniques including overlaying graphically displayed data layers, displaying the results of mathematical formulations used to describe physical relationships, and compiling and translating graphically displayed information into tabular form. Maps of different scales may be digitized and GIS can enlarge or reduce them so that they may be overlaid. GIS may be used interactively, a feature which is especially important for planning exercises. Decision makers are able to sit at the terminal and ask 'what if...' questions of the computer and observe the solutions to these questions almost instantaneously. In the same way, projects may go through an iterative process of refinement with minimal additional effort.

The CCAMP GIS effort utilized the ARC/INFO GIS software package developed by Environmental Systems Research Institute (Redlands, CA). The ARC portion of the package maintains the spatial location of map features such as lines, points, and polygons, while the INFO portion stores and processes an unlimited amount of attribute information which describes these features. The ARC/INFO software was used on a Prime 9955 mini-mainframe computer at the Water Resources Division of the USGS.

B. Project Objectives

The primary project objective was to demonstrate the usefulness of GIS technology in assessing risk to public water-supply wells from different types of contaminants. This included an assessment of the impact from existing sources of contamination in proximity to the wells, as well as facility siting to minimize future risks to wells. An integral component of this demonstration was an evaluation of the data requirements necessary to utilize GIS. Project participants also felt it important to undertake the project with existing facilities and staff in order to demonstrate the ability of other interested parties to employ GIS technology within their agencies. Consequently, an existing computer system was utilized, agency staff were trained and provided in-kind service to the project; no contract funds were used.

The focus of the project was on the analytic capabilities of GIS, not on data collection efforts. For the most part, existing data bases were utilized and there were minimal new data collection efforts. (Prior efforts in CCAMP concentrated on data collection.) Data gaps were noted, but were not generally filled unless the missing information was deemed essential. Scenarios were developed to illustrate the various capabilities of GIS and were specifically designed to:

1) Illustrate the ways in which data on a variety of factors, such as hydrologic, geologic, land use, and environmental conditions, could be integrated;

2) Illustrate spatial relationships between wells, land uses, and contaminant sources;

3) Analyze the risk posed from these activities;

4) Develop management approaches based on risk assessments;

5) Compile a comprehensive database from a variety of existing sources; and

6) Document problem areas in applying this technology including assessing accuracy and completeness of data as well as difficulties which arose in data manipulation.

The final purpose, in keeping with the 'demonstration' nature of the project, was to design the project in such a way that the results could be transferable to others interested in the application of GIS technology to ground water management issues.

C. Organization

A cooperative team including members from each of the CCAMP participating agencies was responsible for the GIS demonstration project. The team was comprised of technical, scientific, and management personnel. Computer technicians, hydrogeologists, and planners all played integral, but different, roles in the project. U.S. Geological Survey computer facilities were used and the Geological Survey staff contributed expertise in operation of the GIS system. This included digitizing maps, inputting attribute data, generating appropriate graphical displays of the analytic scenarios, and training others to assist in these tasks. EPA and Massachusetts DEQE provided technical staff with an understanding of data management issues who were responsible for working with the GIS system as well as evaluating and verifying the data, identifying gaps, and discrepancies. Management staff from these agencies helped to identify important data coverages. They also supported conceptualization, development and, interpretation of risk management scenarios. There was a great deal of interaction between all of the participants and also with other CCAMP work groups in undertaking each of these tasks.

Throughout the previous year, CCAMP had been involved in an extensive land use study for one zone of contribution within the Town of Barnstable. A great deal of data on potential contaminant sources were collected and existing hydrogeologic maps were refined as part of this study. This became the basis for the GIS effort and many of the same people were involved in both projects, creating an important sense of continuity.

III. DATA ACQUISITION

Data acquisition was a major element of CCAMP's GIS project. This section presents the project's approach to obtaining base maps and for compiling and verifying the data associated with ground water management.

A. Choosing Base Maps

The first step in initiating the project was to obtain base maps of the three areas of analysis: Cape Cod, the Town of Eastham, and Zone of Contribution (ZOC #1) in Barnstable. Because ZOC #1 includes portions of both the towns of Barnstable and Yarmouth, two different base maps of comparable detail were needed to cover this area. Considerations in choosing base maps included scale, accuracy, level of detail, currency, and consistency with other town information.

As demonstrated by Figure 2, it was not always possible to find consistent, good quality maps based on these criteria. The base maps and feature maps came from a variety of sources, were of various scales, were created at different times, and were both digital and nondigital. The reasons for these variations are important. The towns of Barnstable and Eastham are at different levels of sophistication in terms of mapping. Most maps produced and maintained by the towns were created for informational or thematic purposes for a specific project or study. In addition, each town has developed its own type of base map and the detail reflects the level of analysis needed to make a decision or undertake a project.

The map of the Barnstable ZOC, including portions of Barnstable and Yarmouth, required the most detailed level of analysis. Because a substantial amount of attribute data stored in the INFO portion of ARC/INFO was referenced to individual parcels, it was important to choose a base map that could support the same level of detail. Consequently, town tax assessor maps outlining each land parcel were chosen as base maps. However, these maps were not geographically referenced nor were the individual parcels drafted with any degree of consistency or accuracy. The end result was the creation of a picture of the area, not a map. It was a useful picture for most of the data related to map and parcel, although it was not possible to locate specific activities within a large parcel.

The second level of analysis was at the town level. Again, town base maps were chosen according to their accuracy, scale, and ability to conform with other data layers. Generally, USGS topographic maps were utilized as

FIGURE 2

MAPS USED IN THE GIS PROJECT

MAP	SOURCE	YEAR	SCALE	FORMAT
CAPEWIDE				
Coastline	USGS	1987	1:25,000	Line/digital
Primary transport	USGS/MADPW	1985	1:190,000	Line/digital
Water Contours	USGS/EPA	1979	1:48,000	Line/paper
Ground-water flow	USGS/EPA	1979	1:48,000	Line/paper
Town boundaries	USGS	1987	1:25,000	Polygon/digital
Cape ZOCs	CCPEDC	Unknown	1:48,000	Polygon/paper
Waste sources	DEQE	1985	1:25,000	Point/digital
Geographic names	USGS	NA	NA	NA
BARNSTABLE/ EASTHAM				
FINDS (Barnstable)	EPA	1986	1:25,000	Point/digital
Wetlands (Eastham)	DEQE	1984	1:5,000	Polygon/orthophot
Zoning	town	1960	unknown	Polygon/paper
Town owned land	town	unknown	1:20,000	Polygon/paper
Commercial land	town	unknown	1:3,600	Polygon/paper
Eastham water quality	town	1984-86	1:3,600	Polygon/paper
ZOC #1				
Assessor maps	Barnstable	1986	1:7,200	Polygon/mylar
	Yarmouth	1980	unknown (app. 1:5,000)	Polygon/paper

base maps. Other town maps, including zoning maps, were not geographically referenced and did not represent a cartographically accurate view of the area. The final level of analysis, the cape-wide maps, were the easiest to obtain and digitize, and generally most accurate. The cape-wide base maps were acquired from the Boston USGS office in digital form. Some of the other large scale databases, especially the waste source data, contained locational errors; while the obvious errors, such as landfills in the ocean were corrected, these data were not field verified for accuracy.

The maps for this project came from a variety of sources and considerable time was spent evaluating them. Other GIS users undertaking ground water analyses should expect to spend considerable effort matching maps of different scales and evaluating the accuracy and appropriateness of various maps. Certain cartographic issues that consistently arose in this CCAMP project should be considered by other GIS users. These include:

- Maps that are not geographically referenced (that is, not referenced to a true location on the ground, such as a latitude-longitude coordinate);
- Maps of various scales and resolutions;
- Maps from various sources;
- Maps in poor physical condition (for example, maps that are folded, wrinkled, or torn); and
- Maps that are out of date.

CCAMP elected to utilize available maps in order to minimize data collection time. Others who are investing in the long term use of GIS may choose not to compromise data quality by utilizing maps which are of poor cartographic quality and may instead wish to spend additional effort in obtaining or creating high quality maps.

B. Data Sources and Automation

The attribute data compiled and utilized for the GIS project were gathered through field investigations and from local and state program files. Refer to Figure 3 for a full list of data sources utilized in this project. A major portion of the attribute data for Barnstable was brought together as part of a land use study in the Barnstable Zone of Contribution #1 undertaken by CCAMP prior to the GIS effort. (See Gallagher, T., Steppacher, L., The Management of Toxic and Hazardous Materials in a Zone of Contribution on Cape Cod, Proceedings of the National Water Well Association FOCUS Conference, 1987, Burlington, VT). As part of the land use study, field surveys of the ZOC were made in order to identify the location, land use, and occupant name of each parcel. Their data were then used as a basis to index other information. Additional field surveys and interviews were undertaken to

FIGURE 3

DATA COVERAGES AND SOURCES*

DATA	SOURCE	COMMENT
POINT COVERAGES		
underground storage tanks	DPS/FDs	
question 4/21E sites	DEQE	
public water-supply wells	DEQE	
large private water supplies	EPA/DEQE	E'ham only,non-community wells
waste sources	DEQE	
FINDS	EPA	
local water quality data	CCPEDC	E'ham only, private wells
municipal sewage disposal discharge	USGS	Barnstable WWTP
right to know data	DEQE	
public water-supply test sites	DEQE	cape-wide,validity questioned
small quantity generators	DEQE	
SPOT	DEQE	
geographic names	USGS	
toxic and haz. material storers	BHD	
class V underground injection wells	EPA/DEQE	field survey, Barn ZOC only
LINE COVERAGES		
primary transportation routes	USGS	
water table contours	USGS/EPA	cape-wide(1:48000),Barn ZOC
ground water flow paths	USGS	cape-wide(1:48000),Barn ZOC
town boundaries	USGS	cape-wide(1:25000)
wetlands	USGS	Eastham only
'DRASTIC' contours	EPA	Barn ZOC, results inconclusive
bear ZOCs(ard. indiv. public wells)	USGS	
Cape Cod National Seashore	USGS	Eastham
POLYGON (AREA) COVERAGES		
Barnstable ZOC	CCPEDC	
Town of Eastham	CCPEDC	
parcel maps/land use	CCPEDC	
coastline	USGS	cape-wide (1:190000)
public water-supply service area	CCPEDC	
Cape Cod ZOCs	CCPEDC	
sewered service areas	Barn	Barnstable ZOC
landfills	DEQE	
USGS quadrangles	USGS	cape-wide
zoning	Barn/Eham	
town owned land	E'ham	
FOR ANALYSIS		
CCAMP nitrate model	USGS	

* DPS-Dept. of Public Safety, FD-local fire dept., BHD-Barnstable Health Dept.

Barn - Barnstable, E'ham - Eastham

identify potential underground injection wells may inject wastes into the ground water.

Other data in potential contaminant source including underground storage tanks, toxic and hazardous material storers and disposers, small quantity generators and ground water discharge permittees were then gathered from local and state files maintained in conjunction with the relevant regulatory program files. These data gathering efforts led to a fairly complete illustration of the potential threats facing each parcel of land within the ZOC. Figure 4 presents an example of the results of data gathering efforts for one potential source of contamination - Class V underground injection wells. Class V wells are defined in the Safe Drinking Water Act and include, but are not limited to, floordrains, large septic systems, agricultural drainage wells, stormwater runoff wells). Similar maps for each source were developed.

The resulting databases contained a great deal of information. For example, the databases identified location and name of each small quantity generator and specified the type and quantity of waste hauled. For each injection well, the database identified the type of well and what material was being injected. This information helped to determine the appropriateness of various management schemes, such as cooperative waste hauling of similar commercial/industrial activities within a certain geographic area. Not all of these data were applied within this demonstration GIS effort, although it would be appropriate to utilize more of it in the future for additional analyses.

None of the data obtained through the land use study were originally automated. Most were found on paper files stored in offices and seldom used. As part of the land use study, land parcels and related attributes as well as potential contaminant source inventories, were put on DBASE III files. These files were translated into a readable form for the GIS.

Additional data layers were employed for the town and cape-wide GIS analyses. Most of these were taken from state compilations which included hazardous waste sites, landfills, and public water supplies. These were also paper files and were input directly into the GIS. The primary difficulties in gathering these data were: 1) the data were stored in a variety of locations and was inconsistently maintained; 2) retrieval was difficult because the data were kept on paper files; and 3) many databases were incomplete and not up to date. Figure 5 estimates the time required to undertake the data gathering portion of the project.

C. Data and Map Verification

Computer operators and users of computer generated products recognize the potential problems arising from use of imperfect data and the challenges to the integrity of analyses resulting from incorrect data. CCAMP participants were also aware of these issues prior to commencing the GIS project and developed a data verification approach to address these issues. The sophisticated presentation which the GIS technology is able to make creates a sense of certainty in the information displayed. For this reason, it is

POTENTIAL UIC CLASS V WELLS
AND PUBLIC WATER SUPPLY WELLS
IN THE BARNSTABLE ZONE OF CONTRIBUTION

EXPLANATION

- AUTO SERVICE STATION DISPOSAL WELLS
- INDUSTRIAL PROCESS WATER AND WASTE DISPOSAL WELLS
- INDUSTRIAL DRAINAGE WELLS
- DOMESTIC WASTEWATER DISPOSAL WELLS
- PARCELS
- ZOC

Figure 4

FIGURE 5

GIS STAFF REQUIREMENTS

GIS Project Elements/ Staff Analysis	Staff Responsibilities and Duties	Skills Required and Training Needs	Time Commitment (Man-days)	Comments
Data Gathering and Validating	- Windshield survey in field - On site visits to local and state program offices - Compilation of varied databases - Inspection of UIC wells	- Understanding of whole project, i.e., final data requirements, available data sources	32 man-days	- Time may be under estimated because CCAMP had established cooperation with local offices providing data
Data Automation	- Digitizing maps - Automating attribute files (tables and spreadsheets) - Editing	- Digitizing skills - Training in ARC/INFO software and PRIME hardware - Data transfer between PC and mainframe computer	60 man-days	- Each participant should have introductory training on computer and the software
Date Verification	- Check maps against field surveys, other maps - Proof automated data, check against other data layers - Circulate data to program persons	- Knowledge of the field area - Time	75 man-days	
Data Analysis and Scenario Playing	- Storybook step by step presentation - Iterative refinements - Review of plots - Presentations for comments	- Understanding of GIS - Understanding of ground water concerns - Understanding of risk - ARCINFO training - Strong scientific support for scenarios	40 man-days (does not include input from steering committee)	- Include wider diversity of people early in process - Refine scenarios during data gathering stages

extremely important to support this conceptual security with truly accurate data.

Data verification issues are two-fold: first, one must determine if the data are accurate and truthful; second, one must determine whether the data have been automated without mistakes. The latter requires the time consuming and cumbersome task of checking each data entry with its original, plotting maps to scale, and overlaying with originals and checking for typographical errors. The most difficult aspect of this task in the CCAMP project was ensuring that the more than 1,900 land parcels and related land use identification numbers were correctly located. This accuracy was crucial because it was the base on which many other data layers depended.

The importance of this task, however, was overshadowed by the critical need to ensure that all the data within the GIS were accurate. Ideally, each data file would be verified in the field. If this is not possible, the data should be verified, at best, against a similar file maintained by another entity. This was not always possible in the CCAMP study because of limited time and resources. CCAMP depended on the specific knowledge of project participants and draft plots of data coverages which were reviewed by project managers from whom the data was obtained.

Whenever possible, critical information were cross-checked against other easily accessible data. This approach worked well in Barnstable where local agencies had been involved in collecting data on municipal wells, landfills, and small quantity generators which could be compared to similar state data bases. This was far more difficult in Eastham which does not have the manpower to maintain a similar database at the local level and does not believe their problems justify the commitment needed to develop such a database. Consequently, the state data was assumed to be correct in this case. Numerous discrepancies were identified and corrected through these processes. However, without field checks and more extensive verification, it was difficult to assure the total accuracy of the database. It seemed that a verification process was never pursued in a systematic manner, and errors were uncovered throughout the project.

There were numerous other difficulties encountered in verifying data and maps. One such difficulty was that the accuracy and completeness of the maps and data files varied greatly. For example, the local fire department supplied well organized, up to date records on underground storage tank information. They were also very knowledgeable of the local area and cooperative to CCAMP participants, assuring a complete database. However, other files provided to CCAMP were incomplete, out of date, and poorly organized. Many were of such poor quality that it was difficult to read them. Additionally, activity locations were "Xed" on large scale maps, sketches, or plans providing only a general idea of the actual location.

The overriding reason for poor quality files appeared to be that program files were seldom used by analysts or decision makers in other programs. Similar data gathering efforts are often undertaken simultaneously by various programs or agencies for specific purposes. Unfortunately, CCAMP found that

inconsistent data were being maintained by different agencies. It was nearly impossible to resolve these problems without field verification.

One response to the variability in data quality was to develop a data dictionary. This is a compendium of each data source containing information, for example, on where it is housed, the purpose for which it is gathered, who gathered it, who maintains it, the medium (paper or automated), and the scale. While this did not solve inconsistencies or correct data problems, it clearly identified the important 'vital statistics' needed to evaluate data sources against each other, assessed their applicability to the project and identified a contact person if any questions arose regarding the database. It is recommended that any GIS project should maintain a similar data dictionary, especially long term projects with a multitude of databases.

IV. SCENARIOS

The emphasis of the demonstration project soon changed from a data gathering/inputting/verifying process to analysis and evaluation. This shift reemphasized what had been learned; the data could use many further improvements, and if it were to be used as the basis for policy decisions, further verification would certainly be required. Because this project had been initiated to identify the applicability of the technology, noting any shortcomings it may have, the data were employed to demonstrate the usefulness of the technology without additional verification beyond that already described.

Knowing the data available and applying their own understanding of ground water management issues, each team member developed one or more 'scenarios'. A scenario for the purpose of CCAMP, was defined as a process of overlaying and displaying various geographic data while interpreting and analyzing the relevant attribute data in order to illustrate some aspect of the risk related issues. These scenarios were reviewed and prioritized by the team. Prioritization was based on both the perceived need for the analysis and an assessment of how well GIS could display the issue. There was an initial bias to work on scenarios which would best demonstrate the mapping and analytic capabilities of GIS.

Sixteen scenarios were initially proposed as listed on page 15, Figure 6. While these scenarios illustrate the wide range of possible analyses which could be undertaken with the data available, eight of these scenarios were chosen for in-depth work. The eight selected scenarios address issues such as siting of contaminant threats to reduce risk, setting of priorities for cleanup activities, and management of existing activities that may threaten ground water. Additionally, the eight scenarios address important issues currently being discussed within the towns and the state. The next section presents each of the scenarios. The purpose of each scenario is presented first and is followed by a brief summary of the conclusion and the use of GIS. Following Figure 6, Figure 7 explains the specific steps taken in each selected scenario to arrive at the final map. A copy of each of the final maps may be found at the conclusion of this report.

FIGURE 6

SIXTEEN PROPOSED MANAGEMENT SCENARIOS

- Identify future public supply well sites for Eastham and determine zones of contribution for these wells.
- Identify stump dump/demolition waste sites for Eastham which will minimize threats to ground water.
- Model future nitrate levels in supply wells resulting from saturation development at current zoning and impacts of revised zoning.
- Design an effective monitoring network to protect against existing hazards.
- Determine comparative risk of contamination of public supply wells from existing contamination sources (underground storage tanks, toxic and hazardous materials, etc.)
- Examine risk from underground storage tanks by looking at age, capacity, location, etc.
- Determine land use management/growth scenario in Eastham that protects private well water quality.
- Identify appropriate sites for high risk activities.
- Perform a risk/threat analysis of hazardous waste sites and water supplies.
- Assess zoning/growth/land use issues in zones of contribution that cross town boundaries.
- Assess implementation of local, state, and federal toxic and hazardous materials regulations.
- Examine transportation of hazardous substances in relation to public water-supplies.
- Determine priority areas for sewering.
- Develop cape-wide map of zones of contribution and major waste sites.
- Examine effects of 400 foot protection radius versus 2000 foot.
- Examine contaminant transport/protection distances.

FIGURE 7

OUTLINE OF SCENARIO PROCESS

Scenario	GIS Steps	Reason for Step
1. Identify a site for a 1 MGD water-supply in Eastham	1. Base map of Eastham	
	2. Identify commercial properties and place a 400 foot radius around them.	- Identify known potential threats to water quality - Eliminate such areas from consideration
	3. Buffer Rt. 6 with 400 feet.	- Buffer distance based on DEQE regulations
	4. Buffer all ponds and wetlands with 150 feet.	- Eliminate from consideration based on sensitivity of ground water pumping impacts on surface water
	5. Identify all town owned parcels of at least five acres.	- Provide town with as much control over land use as possible
	6. Eliminate town parcels within the Nation Seashore.	- National Seashore rejected location of water-supply well within boundaries. But note that Seashore can provide protection from development to adjacent properties.
	7. Identify all private wells. (optional)	- Extra information. To identify feasible areas for delivery system and make preliminary cost estimates.
	8. Delineate assumed zone of contribution and the newly required half mile radius. (optional)	- Compare protection afforded by state policy versus actual contributing area.
	FINAL RESULT: Map of Eastham identifying assumed zone of contribution (Figure 8)	
2. Identify a site for a stump dump for Eastham	1. Base map of Eastham	
	2. Identify commercial properties, ponds, wetlands, roads, and buffer as in Scenario 1.	- Buffer distance based on DEQE regulations
	3. Identify and eliminate from consideration National Seashore property, residential properties, proposed new water-supply zone of contribution.	- Eliminate from consideration all incompatible land uses
	4. Identify town owned parcels over 5 acres.	- Provide town with control over land.
	5. Overlay water table contours and flow directions.	- Minimize pollution potential to sensitive areas by placing dump down gradient.
	6. Display parcels which are potential sites for stump dump.	
	FINAL RESULT: Map of Eastham identifying possible stump dump site (Figure 9)	

FIGURE 7

OUTLINE OF SCENARIO PROCESS

Scenario	GIS Steps	Reason for Step
Barnstable Zone of Contribution	MAP 1	
	1. Zone of contribution outline.	
3. Inter-town management in Barnstable zone of contribution	2. Overlay individual zones of contribution (Bear ZOCs)	- Identify portions of individual zones of contribution which cross town lines.
	3. Overlay zoning map	- Identify how zoning differs across town lines.
	MAP 2	
	1. Outline of zone of contribution.	
	2. Overlay individual zone of contribution.	
	3. Overlay existing land use map.	- Identify how land is actually used.
		- Identify land uses which threaten water quality.
		- Note conflicts across town lines.
	MAP 3	
	1. Overlay zoning and land use maps.	- Identify those areas where land use is not in accordance with zoning to be used to target attention.
	2. Compile percent of different land use and zoning types in each town.	- Optional. To illustrate character of town.
	FINAL RESULT: Map of ZOC identifying those parcels where land use is different than zoning. (Figures 10 and 11)	
4. Implication of Full Development in Barnstable Zone of Contribution	MAP 1	
	1. Base map of ZOC.	
	2. Categorize land use into one of 15 groupings based on relative risk posed to ground water.	- Based on best professional judgment. Aggregate over 100 land uses into 15 categories based on potential risk to public water-supply.
	3. Overlay categorized land uses.	- Using various shadings, can identify location and extent of risky activities.
	MAP 2	
	1. Base map of ZOC	
	2. Assume all land with growth potential is developed according to existing zoning ordinance.	- In high growth area with no zoning changes this represents full development.
	3. Overlay full development map on ZOC.	- Identify location and degree of potential risk.
	4. Categorize each potential land use according to risk, as defined above.	

FIGURE 7

OUTLINE OF SCENARIO PROCESS

Scenario	GIS Steps	Reason for Step
Scenario 4, continued	5. Calculate percent change in land use type before and after full development.	- Compare graphically and analytically, risk posed presently and from full development. - Identify increased risk. - Identify incompatible land uses and zoning designations over town lines.
	FINAL RESULT: Two maps, first identifying existing land uses colored by risk posed, second identifying ultimate development land uses also colored by risk category. (Figure 12)	
5. Application of nitrate loading formula within Barnstable ZOC	1. Base map of ZOC.	
	2. Categorize land uses into 8 groupings based on relative nitrate contribution.	
	3. Assign values of nitrate generated to each land use category.	- Categories and values are based on literature and included in report by Frimpter, et. al.
	4. Calculate number of parcels in each category.	
	5. Apply equation for calculating total nitrate load.	
	6. Shade categories and plot on ZOC map.	
	FINAL RESULT: ZOC map identifying those parcels contributing to the nitrate load. Accompanying map is a chart indicating individual nitrate loads used in the analysis. (Figure 13)	
6. Ranking of risk posed by underground storage tanks in Barnstable ZOC	1. Outline of individual ZOC surrounding Maher Diesel Wells (also called Bear ZOC).	- Because distance is an important criteria, need to make assessment from localized area.
	2. Delineate time of travel contours.	- Display graphically the distance corresponding to time of contaminant travel to well.
	3. Rank each tank according to six attributes and sum rankings.	- Distance, tank age, size, content, construction material, urbanization of area.
	4. Categorize rankings into high, medium, and low with corresponding color scheme.	
	5. Plot tanks according to risk.	- To display relative risk posed by each tank.
	FINAL RESULT: Map of individual ZOC with time of travel contours identified and individual UST plotted by color. (Figure 14)	

FIGURE 7

OUTLINE OF SCENARIO PROCESS

Scenario	GIS Steps	Reason for Step
CAPE COD		
7. Ranking of risk posed by landfills on Cape Cod	1. Base map of Cape Cod with town boundaries.	
	2. Overlay public supply well locations and corresponding ZOC delineations.	
	3. Overlay landfill locations.	- Distance from landfill to ZOC and well is important factor in ranking scheme.
	4. Calculate distance of landfills from ZOC and well.	
	5. Assign a weight to each landfill attribute to be used in ranking.	- Distance, also depth to water table, liner, leachate collection system, water table gradient, thickness of overburden, nature of material.
	6. Rank each landfill according to seven weighted attributes and sum ranking.	- Weights are based on professional judgment.
	7. Categorize risk into high, medium, and low and assign color related scheme.	- See ranking in Figure 14.
	8. Assign Appropriate risk category to each landfill.	
	FINAL RESULT: Map of Cape Cod, all ZOCs delineated and each landfill plotted and color coded according to risk. (Figure 15)	
8. Assessment of policy to management programs based on 1/2 mile radius around those wells without delineated ZOC	1. Base map of Cape Cod town boundaries.	
	2. Overlay public water-supply wells and corresponding delineate ZOCs	
	3. Overlay calculated 1/2 mile radius around each public supply wells.	- Observe difference in area and determine whether 1/2 mile radius over or under protects the water resource.
	FINAL RESULT: Map of Cape Cod, all ZOCs delineated and 1/2 mile radius overlaid. (Figure 16)	

TOWN OF EASTHAM

Scenario 1. Identify a site for development of a 1 million gallon per day public water supply system to serve the Town of Eastham.

Purpose: The town of Eastham, rural and residential in character, presently is served solely by private wells. There have been localized incidents of ground water contamination due to the landfill, commercial activity, and high nitrogen levels in densely populated areas. Because the town is growing at a significant rate, increased activity could lead to a greater risk to the private wells. In order to ensure the possible future delivery of high quality water, an appropriate site suitable for a municipal well, i.e., one which is hydrogeologically capable of producing 1 MGD and which has minimal existing threats, should be located.

Conclusions/Applicability of GIS: Siting decisions are probably one of the most commonly illustrated and convincing applications of GIS technology. This scenario was able to identify all potential sites defined in this scenario as town parcels over 5 acres. Utilizing a series of overlay maps, existing incompatible activities in proximity to the sites were located. Any site with adjacent incompatible activities was eliminated from further consideration. Two sites were identified to be protected for future use.

Data requirements for this scenario were moderate; most of the data were available from local town files. Perhaps the least reliable was the hydrogeologic data used to identify zones of contribution to potential wells. More site specific information will be required in future work on the development of the water supply source.

Scenario 2. Identify a site for a stump dump for the Town of Eastham.

Purpose: In conjunction with the Scenario 1 analysis to identify a public water supply well, the Town of Eastham requested that CCAMP undertake a related investigation to locate an appropriate site for a stump dump. The timing of the analysis has enabled Eastham to identify a stump dump site which will be compatible with, or minimize the threat to, a drinking water well.

Conclusion/Applicability of GIS: This analysis was very similar to that undertaken for Scenario 1; a series of overlays were utilized to identify the most appropriate location for a stump dump. Both hydrogeologic and land use consideration were included in the analysis. GIS was able to assimilate the data and display the conclusions effectively.

BARNSTABLE ZONE OF CONTRIBUTION

Scenario 3. Inter-town management issues within the Barnstable Zone of Contribution.

Purpose: The Barnstable Zone of Contribution #1 illustrates that hydrogeologic boundaries do not respect political jurisdictions; the ZOC

straddles the town line between Barnstable and Yarmouth. Although water from this ZOC serves the Town of Barnstable, land use activities in Yarmouth may affect its quality and Yarmouth may not recognize this area of town as a high priority for enforcement of town codes. This situation requires strong channels of communication and cooperation (as was noted in other portions of CCAMP project). The propose of this scenario is to graphically represent the existing situation as well as the planned futures of the ZOC, based on current zoning, and utilize this as a starting point for inter-town discussions.

Conclusion/Applicability of GIS: While the analysis itself was not rigorous, the graphical representation generated clearly met the objectives of the scenario. The maps were able to move a conceptual idea of the need for inter-town management to a concrete starting point for discussion and negotiation based on specifics. Because the land use data were available at the parcel level, individual nonconforming uses could be identified and targeted if required, for local enforcement efforts. In both towns, overall development plans are not fully consistent with ground water protection. The simple overlay of zoning on the ZOC map identified incompatible future land uses and may be utilized to channel efforts at rezoning in both towns.

Although not utilized its full potential, GIS technology can be used effectively in the capacity illustrated in this scenario. One limitation is the amount of time required to accurately gather and digitize land use data by parcel. If these two data layers were digitized solely to be used in this scenario, it would have been more efficient to do the analysis manually, but because these data layers were used frequently, GIS has the advantage over manual mapping of generating additional maps easily and quickly.

Scenario 4. Identify potential risk to public water-supply wells from complete planned future development.

Purpose: With the existing rate of growth on Cape Cod, some planners believe that all allowable possible development will ultimately occur. A zoning ordinance and map is not just a guide to the future in this situation, but a map of what will occur. This 'build-out' analysis is not a projection in that a time element is not included; it is an illustration of full growth, at some unidentified future point in time. Portions of the Barnstable zone of contribution are already developed and water purveyors are in the business of managing existing risks. However, there are a number of large undeveloped and partially developed parcels north of Route 6. These parcels (when developed) could significantly increase the risk posed to the public supply wells.

In this scenario, a simple ranking of land uses and zoning categories according to risk was developed. It was applied by assigning different shades of color to different levels of risk, first to existing land uses and then to potential development based on zoning. Differences between the map of risky activities in the ZOC now and those which will be there in the future were noted. The purpose was to present the consequences of taking no further action to limit land uses in a zone of contribution.

Conclusion/Applicability of GIS: When full development is reached in this ZOC, the water purveyors will be in the business of managing a high risk potential public water-supply. Figure 11 clearly depicts the substantial increase in risk resulting from development of many vacant parcels north of Route 6 presently zoned industrial.

This kind of presentation, utilizing GIS map making abilities, can be a strong tool in discussing with decision makers the need to consider rezoning. Existing zoning can be altered slightly and the resulting decrease in potential risk can be viewed. It is important to remember, however, that the professional quality of the maps carries with it an appearance of certainty that is not always there. When CCAMP presented this scenario, many individuals believed that CCAMP was projecting that full development would occur. It is important to title and qualify maps explicitly to reduce these misunderstandings. The maps should be utilized as a catalyst for change.

Scenario 5. Application of predictive nitrate loading formula within zone of contribution.

Purpose: A predictive nitrate loading formula was developed by a group of hydrogeologists during an earlier phase of the CCAMP project. The formula is based on a mass balance concept and assigns specific nitrate loads to a multitude of land use activities. It is intended to be used in the planning process to assess the incremental impact of a proposed development on the nitrate concentration at the well. (See "Nitrate Loading in Municipal Wellhead Areas" by M. Frimpter, J. Donahue, M. Rapacz, August, 1988 for a full explanation and discussion).

Because GIS has analytic capabilities it was possible to program the nitrate loading formula into the computer, assign loads to various activities, and generate the load at the well. This then could be coupled with a graphical display of the nitrate for different portions of the zone of contribution. Decision makers could determine the load resulting from a proposed development before approval of the development.

Conclusions/Applicability of GIS: The results of this scenario were slightly compromised because the nitrate loading formula was designed to predict the load within a ZOC surrounding one well. The Barnstable ZOC is a composite including nine wells and it is not totally appropriate to apply the formula in this case. It is difficult to ascertain the accuracy of the application because of the complexities of pumping schemes and consequent ground water flow between the individual wells.

Conceptually, however, the application was appropriate. Additionally, it illustrated clearly the variable loads generated from specific parcels. With more time, the formula could have been applied within each of the individual ZOCs.

Scenario 6. Ranking of risk from underground storage tanks (UST) to public supply wells.

Purpose: An inventory of USTs within the Barnstable Zone of Contribution identified 186 tanks on 82 sites. A number of facts and statistics had been publicized pointing to the potential risk from UST. For example, it has been noted that one gallon of gasoline could render 750,000 gallons of water undrinkable (National Rural Water Association), and any tank over 20 years old has a 57% chance of leaking (EPA). In this zone of contribution, all six of the confirmed hazardous waste sites were due to petroleum contamination. The purpose of this scenario was to illustrate a method using GIS to prioritize management of USTs based on their relative risk to the public supply wells.

When the inventory was undertaken, additional information on each tank was gathered, including age, size, contents, type of tank (e.g., steel or fiberglass), and location. Utilizing GIS functions, the location of the UST was translated into distance from a particular well. All these data were employed as factors in a risk ranking scheme. Each tank was assigned points for each factor which were summed arithmetically to assess overall risk posed by each individual tank. This analysis was done for specific wells so the distance factor could be accurately incorporated. The ranking schemes are presented with the map at the back of this report.

Conclusion/Applicability of GIS: This was perhaps one of the more rigorous scenarios in terms of the ability of the science to keep pace with the technology. Even within CCAMP, there were disagreements on the ranking scheme, and if it had been shown to a panel of experts, several differences of opinion about the method of ranking risk to the well could be expected. Very few studies support the specific categories which distinguish high, medium, and low risk tanks. Additionally, it is difficult to scientifically ascertain the relative contribution of one factor over another to overall risk. However, the GIS technology was able to demonstrate an approach to risk assessment which utilized both analytic and geographic factors in a coordinated way.

In situations like this, where the science supporting the analysis is uncertain, GIS is well suited. It is possible to run and rerun the scenario, each time changing the assumptions on which the scenario is based. Additionally, GIS makes it easy to undertake sensitivity analyses of each of the variables contributing to the risk factor by weighting them in various ways and observing the changes in results. The CCAMP project did not spend sufficient time on this portion of the analysis.

Data quality issues were also extremely important to the integrity of this scenario. This was the first scenario which employed contaminant source data gathered from local and state sources of data (See Gallagher, T., Steppacher, L., 1987, for discussion of inventory, sources of data, and quality issues). The data were available as the result of a new state law and new reporting requirements. Most of the information was handwritten on forms and submitted to the local fire department. It was copied by CCAMP participants and transferred to a DBASE file. Although there was a large

effort to verify data, there were many places for error beyond the control of CCAMP. For example, the one tank which was perceived to pose the greatest risk, in actuality was an above ground tank, but that fact was not indicated in the files.

CAPE COD

Scenario 7. Prioritization of landfills for clean up based on threat to public water-supplies.

Purpose: The State of Massachusetts is presently in the position of enforcing regulations at active landfills and managing the closure of others, with resources far too small to adequately do the job in a timely fashion. Cleanup activities, therefore, must be prioritized. Because landfills are a major threat to ground water quality, it is appropriate to examine individual features of each landfill and prioritize their management based on the level of threat they present.

This scenario, like Scenario 6, develops a ranking scheme based on seven factors which may affect the likelihood that a landfill will threaten ground water, specifically drinking water. Many of the ranking factors are also used in the LaGrand Ranking methodology, including depth to water table, water table gradient, and the nature and thickness of unconsolidated material. Additional factors included size, presence or absence of a liner, and presence or absence of a leachate collection system. Distance to public water supplies, both in and outside zones of contribution, was also incorporated and weighted heavily; distance was considered the major factor influencing potential contamination. In fact, any landfill located within a zone of contribution automatically was placed in the moderate-high or high risk category. The sum of the weighted ranks was determined by multiplying each attribute rank by that attribute's weighting factor to get a weighted rank. Then the weighted ranks are summed for each landfill. The weighted rankings are presented with the map at the back of the report.

Conclusion/Applicability of GIS: As the previous scenario provided insight for UST within a single wellhead protection area, this scenario utilizes a similar approach in a larger region in order to set priorities within a state regulatory program. Together these scenarios illustrate the suitability of GIS to environmental priority setting based on risk. GIS proved to be very capable of compiling extensive data on a large number of individual facilities and applying a standardized evaluation tool to each facility in order to estimate comparative risk. Again, the ranking scheme may not meet the expectations of all scientists and/or analysts; although the LaGrand ranking scheme has undergone professional review and has been employed in a variety of settings.

Data on each landfill were quite easily obtained from the DEQE. Much of it was reported to the State as part of the landfill permitting process. The geographic location of each landfill was the most difficult information to gather and required extensive scrutiny. Because the distance factor was

weighted heavily in the ranking scheme, the accuracy of these locations was critical.

Scenario 8. Implications of a one-half mile radius around a well versus a delineated zone of contribution.

Purpose: To implement some of the institutional recommendations CCAMP had proposed, DEQE wanted to incorporate a resource-based approach to a wide range of regulatory programs. That would mean that program activities designed to protect ground water resources would have a higher priority within ZOCs, the most vulnerable resource area. Because a large number of public water-supplies did not have ZOCs delineated, the state was considering adopting a policy which assumed a one half mile radius around these public water-supply wells.

On Cape Cod, all ZOCs have been delineated so that a graphic overlay of these ZOCs and a one half mile radius could illustrate the different land areas which could be affected and determine the suitability of the policy in meeting the goal of protecting ground water.

Conclusion/Applicability of GIS: A graphical display of this type illustrates the applicability of GIS to planning and policy decision making. GIS enabled DEQE to examine the differences between a scientifically derived ZOC and one created through a policy decision. It also could calculate the affected land area in each situation. The graphic display illustrated that a one half mile radius is conservative downgradient of the well and not as conservative upgradient. However, on Cape Cod the one half mile radius was consistently smaller than the delineated ZOC. This is due to the sandy soils and high transmissivities on Cape Cod. Again, the GIS could have been well utilized in performing sensitivity analyses of various sized radii.

V. LESSONS LEARNED -- RECOMMENDATIONS FOR FUTURE GIS PROJECTS

Because the project was designed to be a demonstration, very careful notes were made of the process undertaken, problems encountered, and future needs so that others could benefit from CCAMP's experiences. The following section highlights the major project findings and recommendations based on these experiences. While supporting evidence is included so that this section may be read independently, it is best understood in the context of the complete report. This is especially true of the data related recommendations. The range of issues related to data are fully explained in the data sections.

1: Identification of Project Goals

Recommendation: Project goals and objectives must be clearly identified and a project design detailed so that specific needs are identified before the project begins. Included in this should be an evaluation of data quality and base map quality. Data quality may dictate the feasibility of meeting certain objectives.

Supporting Evidence: The CCAMP project's objectives were not always specific enough to direct data gathering efforts. Frequently, data layers were gathered and digitized because they were available and in a usable form, not because of the need for them in the analytic phase of the project. Because the scenarios were not developed at the beginning of the project, they did not guide data collection efforts. Instead, available data dictated the level of analysis possible in certain scenarios.

Because specific needs were not clearly defined and data requirements not thoroughly understood, CCAMP underestimated the time commitment needed for developing the data into a usable form. An initial evaluation of data quality would have kept project participants from investing a great deal of time in automating a database which was not accurate and ultimately was not critical in any scenario.

2: Data Quality

Recommendation: Since the quality of GIS products and analyses depends on the quality of the data a GIS is built from, it is essential to choose high quality data sources. All data to be used in a GIS should be adequately referenced by a legitimate geographic coordinate system. For tabular spreadsheet data sets, this means that each data point (well, UST, waste site) should be referenced by a pair of x-y coordinates such as latitude-longitude. For mapped data, this means that the map should be a legitimate cartographic projection referenced by a coordinate system such as latitude-longitude. Source maps should also be in good physical condition (not wrinkled or torn) and on a scale-stable medium such as mylar.

In addition, any GIS project team should include a person who has knowledge of basic cartographic and geographic principles such as projection, scale, and coordinate systems.

Supporting Evidence: With the exception of U.S. Geological Survey 7.5 minute quadrangle maps and Massachusetts Department of Public Works highway maps, most of the source maps used in this project were either lacking in cartographic quality, in poor physical condition, or both. While these maps were appropriate for their initial purposes, they did not contain the ideal qualities of source maps for a GIS.

The base map for the Barnstable zone of contribution, the town tax assessor's parcel map, was not in a legitimate cartographic projection or coordinate system. Parcels were represented schematically; they were not tied to ground-accurate positions and were not accurately represented in size or dimension. Therefore, a number of contaminant source databases, such as the Facility Index Data System (FINDS) which were correctly referenced by latitude and longitude, and a number of data layers such as roads and town boundaries which were taken from good cartographic bases, did not precisely overlay the inaccurate parcel base map.

Likewise, not all tabular data sets contained proper location coordinates. Some data point locations were addresses, others were parcel

numbers, neither of which can be translated into a precise x-y (latitude-longitude) coordinate position. For example, USTs were located by parcel number only; for a tank to be located in a large parcel such as the Barnstable Airport is highly inaccurate.

3: Use of Digitized Data

Recommendation: Any agency or person collecting data should make the effort to collect and store its data in digital form. Agencies should be encouraged to take the initiative to automate their data from the start so that it is readily available for use in a GIS or other computer based application. As far as possible, all databases should be automated before being used as part of a GIS project.

Supporting Evidence: Data related aspects of GIS can be so time consuming that it is not efficient to use staff time to automate paper files. In the CCAMP project file automation distracted personnel from the focus of the project. If certain databases are critical, they should be identified during the planning phases and automated before the project begins. Additionally, data that exist merely on sheets of paper are drastically limited in their applicability, their ability to be shared or transferred to other agencies, and in their ability to be maintained and kept current.

4: Master Version of Data Set

Recommendation: A master version of every data set should be maintained by one person, or one person should be responsible for the status of the data.

Supporting Evidence: In the CCAMP project, a team of people were responsible for the development and maintenance of data. Frequently, there were numerous versions of the same database in existence at one time on different computers. This led to some confusion, because various people made revisions or updates that were not replicated in each version of the data set.

5: Data Dictionary

Recommendation: Vital statistics on the databases should be kept in a 'data dictionary'. It should include the data source, format, medium (paper, mylar, automated), most recent update, level of accuracy, and contact person. The data dictionary should also indicate how each data layer is intended to be used and its limitations.

Supporting Evidence: A data dictionary was developed part way through the project and helped to document where the data were obtained and by whom and in what form. The data dictionary provided a good reference for the scenario conclusions as they are presented to decision makers. Frequently, the validity of the data may be questioned and the dictionary provides full details on each data source. Additionally, for an ongoing GIS effort, the data dictionary may be used as an index to the system and may be utilized to guide analyses.

6: Data Conventions

Recommendation: The State of Massachusetts should further encourage development of data conventions and support the construction of highly accurate statewide databases. Other states should develop data standards, including field verification, to be used by state and local agencies involved in data collection.

Of note is that the Massachusetts Executive Office of Environmental Affairs has established a base scale of 1:25,000 for the Massachusetts statewide database now under construction, and has committed to the National Map Accuracy Standards adhered to on the U.S. Geological Survey 7.5 minute quadrangles which are the base maps for the Massachusetts GIS database.

Supporting Evidence: Data quality standards help to assure a certain level of accuracy in the data used in a GIS project. These standards should help to determine how the data can be used and the degree of reliance to be placed on the analyses utilizing these data. Data standards include guidance on the acceptable sources and format of data guidelines regarding verification of data.

7: Large Scale Maps

Recommendation: The state should encourage and support development of larger scale (i.e., local level) databases, in particular parcel maps that are of good cartographic quality.

Supporting Evidence: Parcel maps provide the most detailed land use information on the level at which zoning, resource protection, and other local policy making decisions are made. The CCAMP project was constantly constrained by the quality of local level data such as parcel based land use, or the total lack thereof. If resource management studies such as CCAMP are to succeed, the development of these data sets must be supported.

8: Staff Expertise with Hardware and Software

Recommendation: Those persons working directly with the hardware and software should be trained in their use prior to project start up.

Supporting Evidence: The CCAMP project was a learning experience for each participant. Only one of the people responsible for data inputting had knowledge of ARC/INFO software when the project began. Instead of placing the responsibility for training on one individual and expecting participants to learn 'on the job', it is important to provide training to all participants during the initial stages of the project. At a minimum, all participants should have been familiar with the PRIME operating system.

9: Staff Availability

Recommendation: The GIS project should be the primary work day focus of project participants.

Supporting Evidence: The CCAMP project depended on numerous participants committing only a portion of their time to this GIS effort. This slowed down the progress and diffused the momentum of the project. It also required that a significant amount of time had to be committed to informing people of the progress of the project.

10: Involvement of Decision Makers

Recommendation: A wide range of policy makers and decision makers should be involved in project design to help identify needs and develop approaches and scenarios.

Supporting Evidence: While the project team was made up of a diverse interdisciplinary group of people, most were at the staff level. The true policy and decision makers should have been more involved throughout the project in brainstorming and critiquing final products. This would have provided important insights to the scenarios early in the project.

Other GIS projects which are not inter-agency in nature may have even a greater need for this involvement. While each participant in CCAMP brought to the project the view point of their particular agency, in a project undertaken by one agency, the GIS study may require a higher level policy maker who could anticipate the perspective of various differing view points on a particular analytic issue.

11: Assess Available Data

Recommendation: All available data sources, especially at the local level, should be assessed at a early point in the analysis in order to develop appropriate strategies for data verification.

Supporting Evidence: The two towns, Barnstable and Eastham, have very different capabilities to gather and maintain data. While local data in Barnstable could be used directly or used to verify state sources of data, Eastham did not have a local data base. Consequently, it was more difficult to find independent data sources with which to verify databases.

12: System for Data Verification

Recommendation: A systematic approach to data verification is essential. This should include:

1. Information exchange between departments and local, state, and federal agencies.

2. Verification of digitized data against original source map.

3. A person with knowledge of the study area to be in charge of verification.

4. Allowance of adequate time in the project schedule.

Supporting Evidence: Data verification consumed significant time and effort. A systematic approach to verification can ensure that the work proceeds as efficiently as possible.

13: Labeling of Maps

Supporting Evidence: Data verification consumed significant time and effort. A systematic approach to verification can ensure that the work proceeds as efficiently as possible.

Recommendation: Place descriptive labels on all map products so there is less chance of misinterpretation. Disclaimers should also be included on all maps with which one cannot be fully assured of the accuracy of the data.

Supporting Evidence: Initial presentations of the GIS products revealed the clarity of the maps to those whom had not been working with them. Generally it was found that map titles were not descriptive enough to fully explain what the map represented. Instead of always having a project participant nearby to explain the scenario, a descriptive text label could have explained the purpose of the map and what it represented.

Additionally, a lot of attention was at these presentations being paid to accuracy of data, especially by persons with a first hand knowledge of it, i.e., landowners. This detracted from the analysis. If verification efforts cannot assure the validity of the data, note should be made of that on the map.

14: Use of Maps for Communication

Recommendation: The maps generated by GIS should be evaluated according to their ability to communicate to an audience what is displayed.

Supporting Evidence: The purpose of the GIS maps is to communicate to others the results of a policy analysis question. Those people generating the maps must consider the best method to convey their results in an understandable way. Frequently the GIS technology enables the analysis to incorporate more detail than can be easily understood. For example, the analyses which categorized land uses into fifteen different categories based on risk assigned a different color to each category. This created a very detailed map which may have been difficult to understand. The conclusions of the analysis may have been more effectively communicated if only six risk categories were presented on the maps.

VI. ASSESSMENT AND CONCLUSIONS

The depth and breadth of the scenario process clearly illustrate the advantages of using GIS technology in ground water protection efforts. The capabilities of the technology provide opportunities and challenges that ground water managers have never faced before in terms of analytic capability and presentation. While the processes are not new to environmental analysts, GIS has provided the capability of quickly undertaking environmental analyses in an organized manner utilizing large amounts of data, and displaying these findings in a clear, professional presentation. Because of the power of the technology and the relative ease of utilizing it, analyses may be driven to a new level of sophistication.

GIS requires a commitment of money, time, and knowledgeable people in order to be effectively applied. The software and hardware costs are significant, but pale next to the commitment of manpower required. The CCAMP demonstration project illustrates the dedication needed to undertake even a moderate level of analysis within a project with limited scope. Figure 5 presented previously, shows each of the critical elements within an application of GIS and the skills and time required to undertake each task. Although a few individuals must understand the software, for the most part, specialized skills are not required. CCAMP's experience clearly demonstrates that a great deal of time and energy is dedicated to data related elements. While this point should be emphasized to anyone considering utilizing GIS, the relative requirements are a bit misleading within the context of this project. More data were gathered and digitized than were actually employed within the scenarios. Initially, sixteen scenarios were proposed which could have been supported with the data available. Additionally, further analysis could have been performed on the chosen scenarios if time had permitted. Consequently, the energy dedicated to data acquisition and input could support a great deal of analysis.

One should also recognize the special circumstances surrounding the CCAMP project which also may have influenced data collection efforts. CCAMP had already established a structure based on the commitment and cooperation of agencies at each level of government. Lines of communication were well established, not only between participating agencies but among all the other agencies. This was especially important in the collection of local data. The CCAMP project was a demonstration of effort and data collection which took place over a limited period of time. A long term commitment to use of GIS in everyday analyses would involve ongoing data collection efforts. In such cases, sufficient time and money could be committed to maintaining an up-to-date database.

Of greater significance, however, is the realization that wellhead protection itself is very data intensive, independent of utilizing GIS as an analytic tool. Analysis is at a small scale and thus requires refined and detailed data. Finding this level of data is difficult at best and ensuring its accuracy can be troublesome. Local governments have gathered data based on their individual needs. Consequently each community maintains data at a

different level of detail. Simultaneously, the state databases do not always include enough detail to effectively undertake wellhead protection. The conclusion is that wellhead protection efforts may require field investigations, such as those undertaken by CCAMP to identify underground injection wells, in order to gather the specific data required to protect the ground water resources. This situation additionally illustrates how the activities required in one regulatory program, underground injection control, complement, and enhance the potential effectiveness of another, namely wellhead protection.

Another key conclusion related to the use of GIS for wellhead protection is the need for accurate data. Because of the professional presentation of the GIS generated maps and the level of detail which can be attained, the margin of error which can be sustained is minimal. The precision of the GIS generated maps presently exceeds that of the quality of the data routinely gathered as part of local and state regulatory programs. Because traditional analytic tools generally have less rigorous data requirements, the use GIS may drive data gathering efforts in the future.

The demonstration indicated that data issues became less critical when the analyses were at a larger scale, i.e., when they covered a larger area. Two scenarios done in the Town of Eastham were quite successful in utilizing the capabilities of GIS to site facilities. Because data required for these scenarios was of a more general nature. The regional analysis of a one half mile radius interim ZOC policy is another example of GIS which produced significant results and was not hindered by data verification difficulties.

Although a substantial portion of ground water management occurs at the local level and GIS has the potential for aiding local decision makers in designing the most effective management tools, the quality of existing data puts a burden on GIS users and challenges the integrity of analyses. Until the time that site specific data meets certain quality standards, GIS is most effectively employed at a regional and state level.

In order to overcome data reliability problems while using available databases, extensive systematic verification efforts are required. It was for all these reasons that CCAMP developed a data dictionary in order to track all sources of data. A data dictionary should be an integral part of all GIS projects, especially those which are ongoing and involve the compilation of a series of databases over time. If data cannot be fully verified then notations should be placed on all maps indicating the potential inaccuracies of the data.

The CCAMP project has illustrated that there are numerous ground water management decisions to be made within regional, state, and federal governments for which GIS provides useful insight. Its utility in setting regulatory program priorities based on protecting the most vulnerable resource areas first has been shown. This kind of analysis could be applied to many program areas. It is the type of analysis which CCAMP advocates in a resource-based approach to ground water protection.

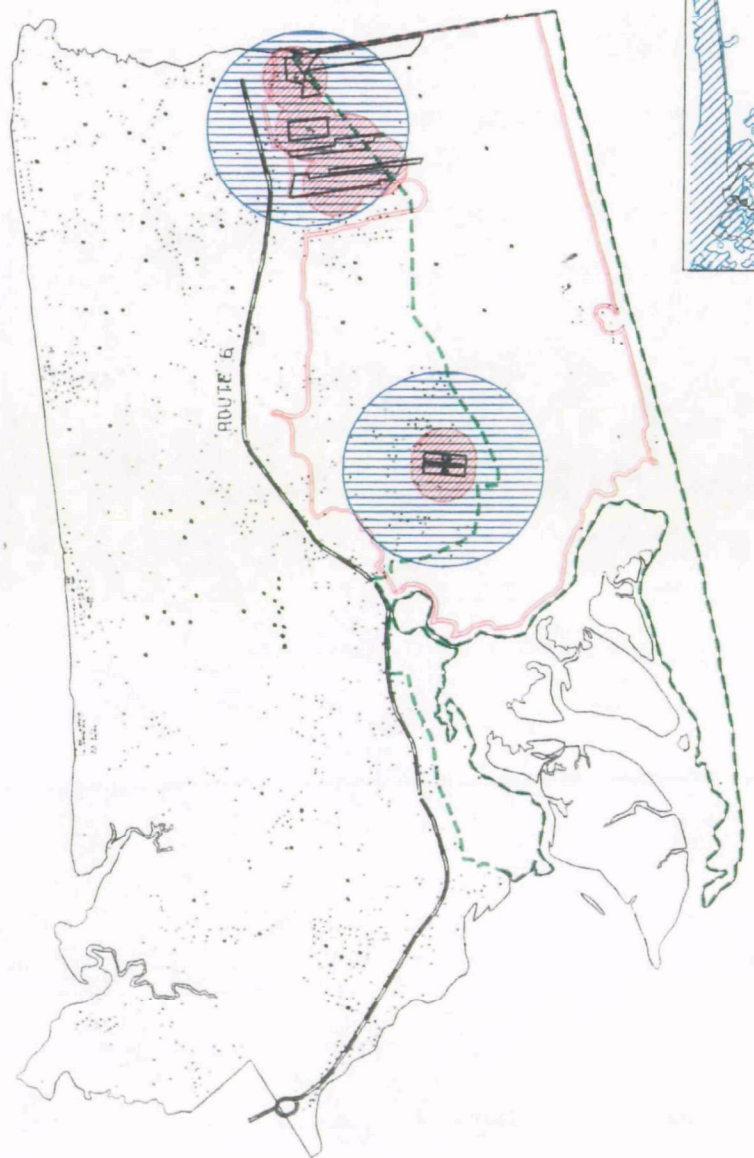
While the scenarios undertaken in this project attempted to prioritize management of contaminating activities within a particular regulatory program, the next step would be to develop a method of comparing the risk posed by different activities, as for example in the comparative risk of landfills, junkyards, and versus historical spill sites. This type of analysis would enable policy makers to set priorities between regulatory programs. GIS would be useful in attempting such an analysis because it is able to manipulate, analyze, and display large quantities of data; although developing an appropriate ranking scheme is still a challenge.

The power of the computer presents many advantages to using GIS over more traditional methods of analysis. It enables the user to generate multiple versions of a mapped product. Consequently, it is easy to correct errors and to refine and update maps as new data and new risk assessment methods becomes available. In the day of paper maps this would have been a cumbersome, time consuming task and possibly would not have been attempted. The interactive capabilities of GIS allow individuals to work at the terminal and ask numerous 'what if...' questions. Answers on the screen, or on a map, are nearly instantaneous. In this way, analysts and policy makers may clearly examine the implications of incremental changes in policy.

The science which may be incorporated into risk based analyses for ground water protection is also in need of advancement. This is not a flaw with the GIS technology but simply reflects limitations on the understanding of physical phenomena related to ground water. In the underground storage tank scenario and the landfill scenario, there was not enough supporting science to document the real threats to the ground water resources and develop a true ranking system. GIS could have incorporated any relationship between the threatening activity and water quality if it had been available.

Time and again CCAMP participants have observed the power of the GIS generated maps as a means of communication. While all maps are generally able to present issues of a geographic nature better than words, the GIS generated maps are of such high quality and are so clear and concise, that the message is easy to grasp. Additionally, the maps generated a great deal of useful, in depth, discussion. Because the GIS utilized data from a variety of offices and programs, representatives from all these programs gathered to examine the products. It was useful in this forum to show individual programs how their concerns overlapped and how ground water protection required cooperation of each of these programs. In this context, GIS appeared to provide results much greater than the sum of its parts.

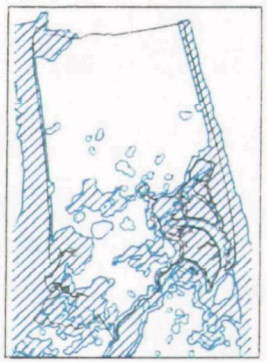
Screening For Potential Public Water-Supply Sites Eastham, MA



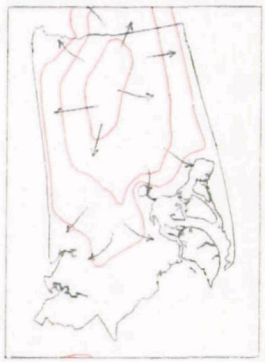
EXPLANATION

- Potential 1 MGD Public Water-Supply Sites
- Locations of Private Wells
- Calculated Zone of Contribution, 1 MGD Well (Radius = 850 ft)
- DEQE Interim 1/2-mile Buffer
- Cape Cod National Seashore
- Boundary of Available Area Passing Screening Criteria for Potential Well Sites
- Town-owned Parcels Greater than 5 Acres

Wetlands and Ponds Buffered 150 ft



Water-Table Contours and Direction of Ground-Water Flow

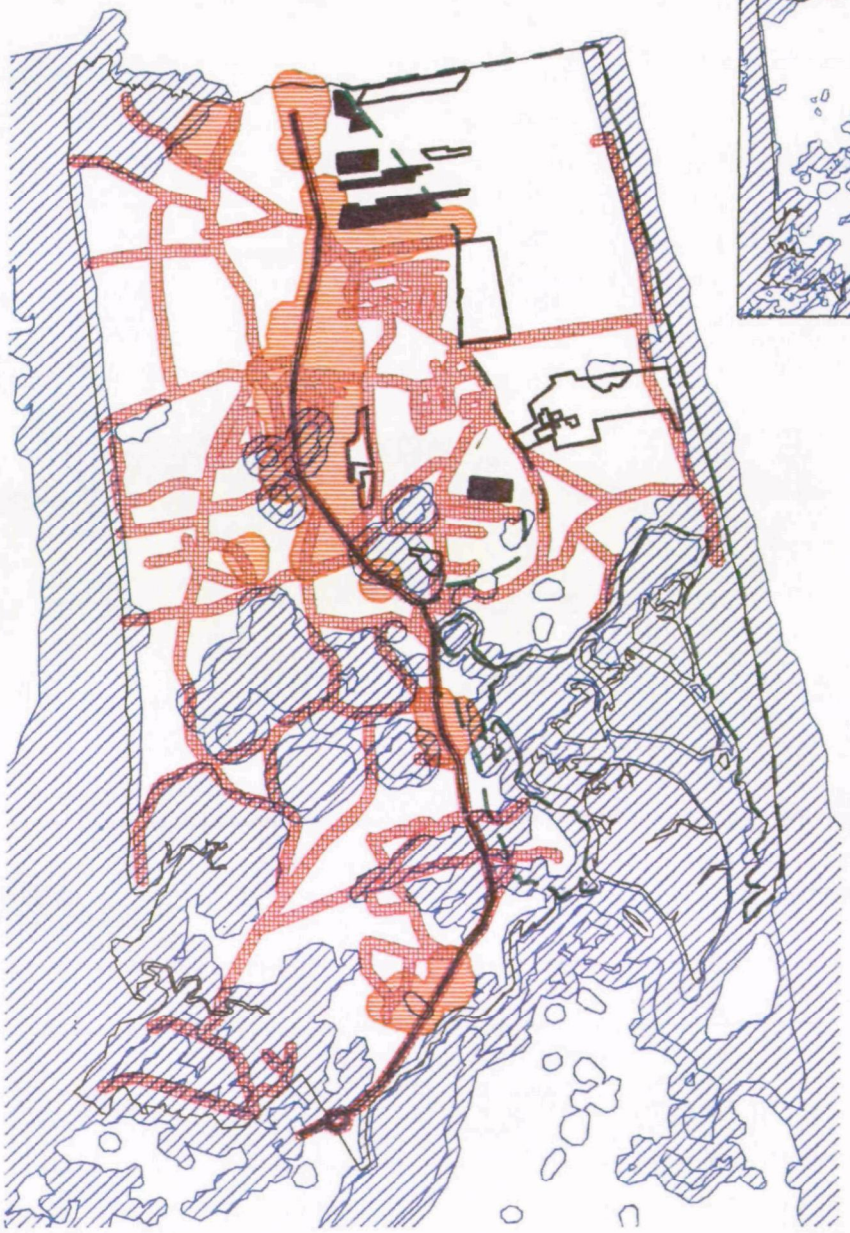


Town-Owned Parcels Greater than 5 Acres

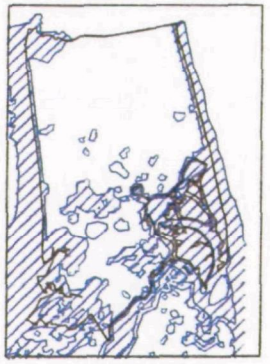
Rte 6 and Commercial Parcels Buffered 400 ft

Figure 8

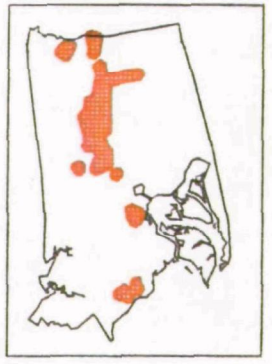
Screening For a Potential Stump Dump Site Eastham, MA



Wetlands and Ponds Buffered 150 and 500 ft

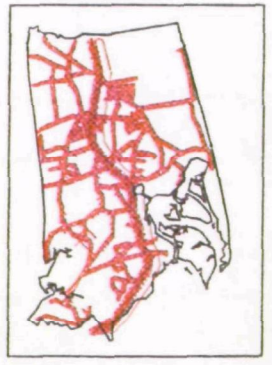


Commercial Parcels Buffered 500 ft



Town-owned Parcels Greater than 5 Acres

Roads Buffered 150 ft



EXPLANATION

- Available Parcels Passing Screening Criteria for a Stump Dump
- Cape Cod National Seashore
- Route 6

Figure 9

Intertown Management: Zoning and Landuse Across Barnstable and Yarmouth Town Boundaries

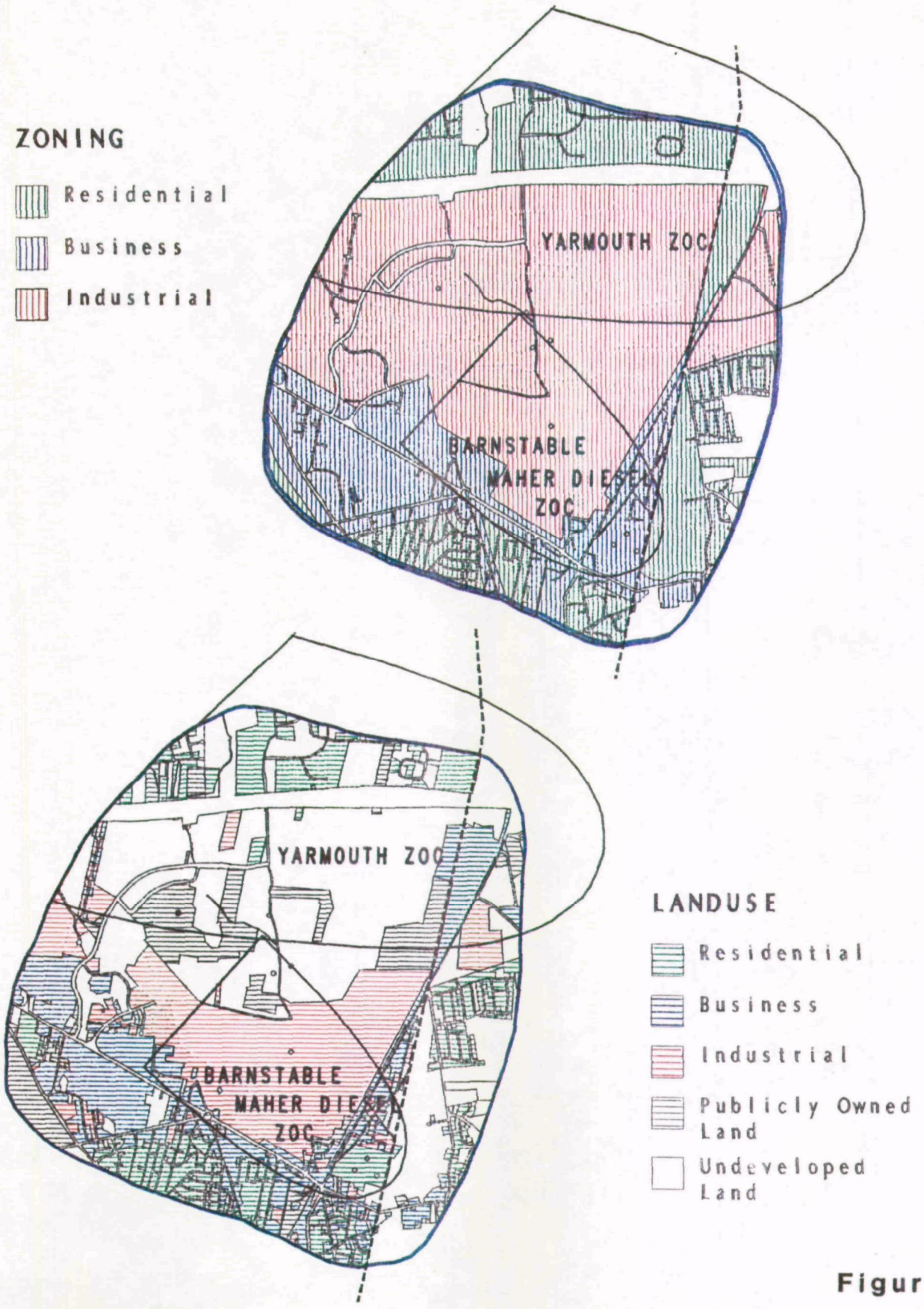
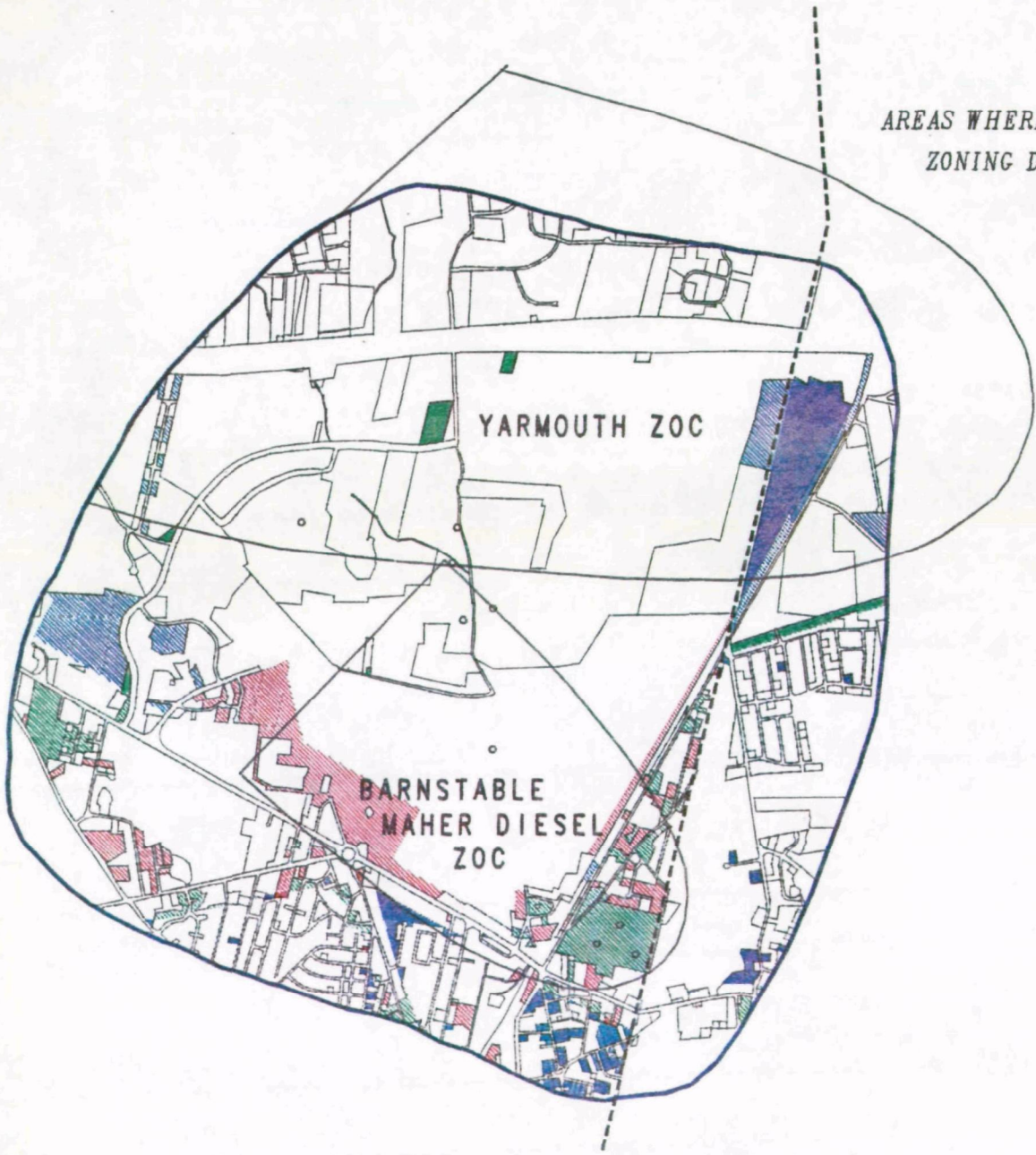


Figure 10

Intertown Management: Zoning and Landuse Across Barnstable and Yarmouth Town Boundaries



EXPLANATION

LANDUSE/ZONING

- Residential/Business
- Residential/Industrial
- Business/Industrial
- Business/Residential
- Industrial/Business
- Industrial/Residential
- Areas Where Landuse And Zoning Are In Agreement, Or Where Landuse Is Publicly Owned Or Undeveloped
- Barnstable Zone of Contribution
- Town-line
- Yarmouth and Maher Diesel Zones of Contribution
- Public Water-Supply Wells

Figure 11

Increase Of Potential Risk To Public-Supply Wells From Landuse Build-Out, Barnstable, MA

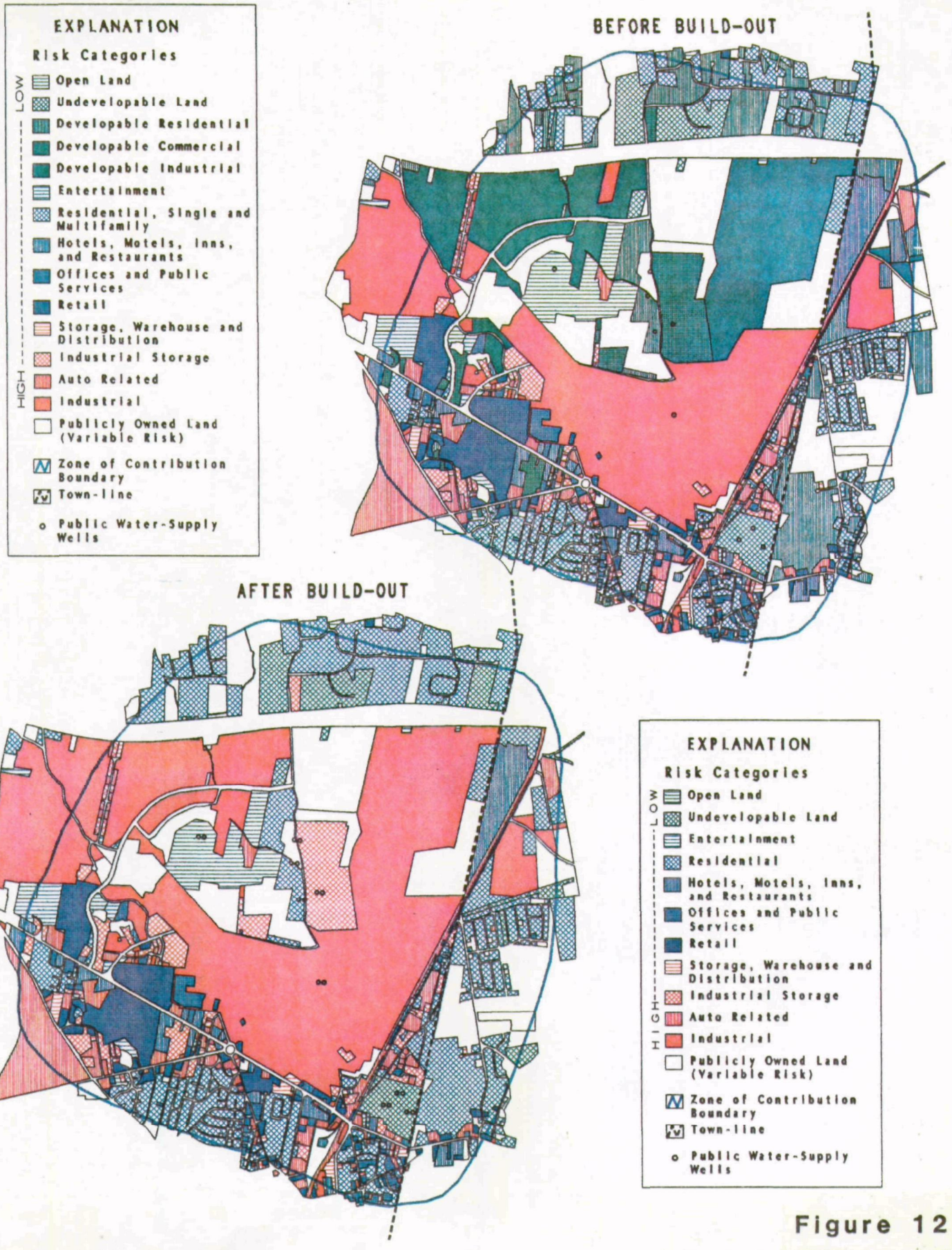
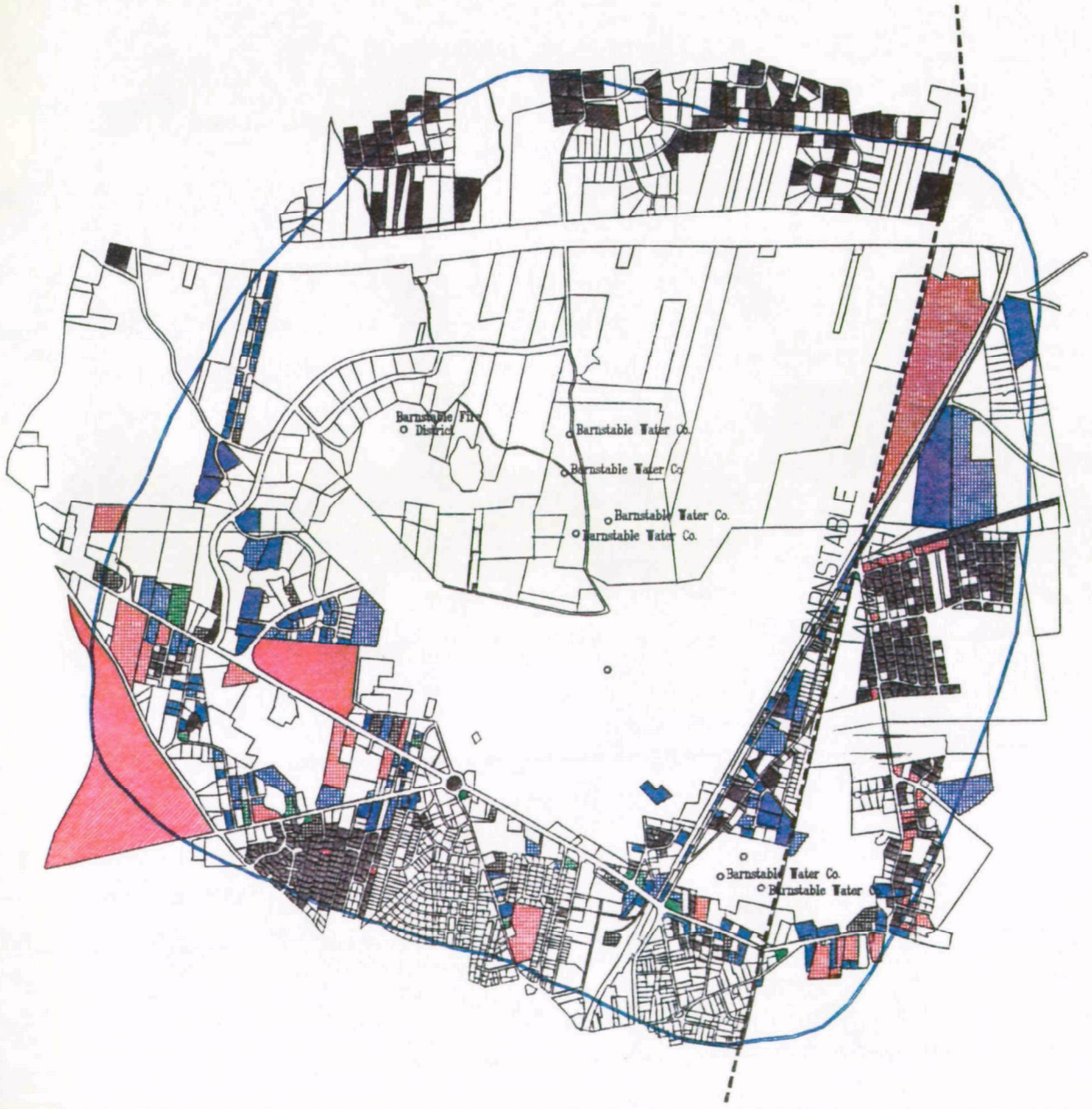


Figure 12

Land-Use-Based Calculation of the Average Nitrate Load to Ground Water within the Zone of Contribution Barnstable, MA



EXPLANATION

Relative Loads From Specific Land Uses

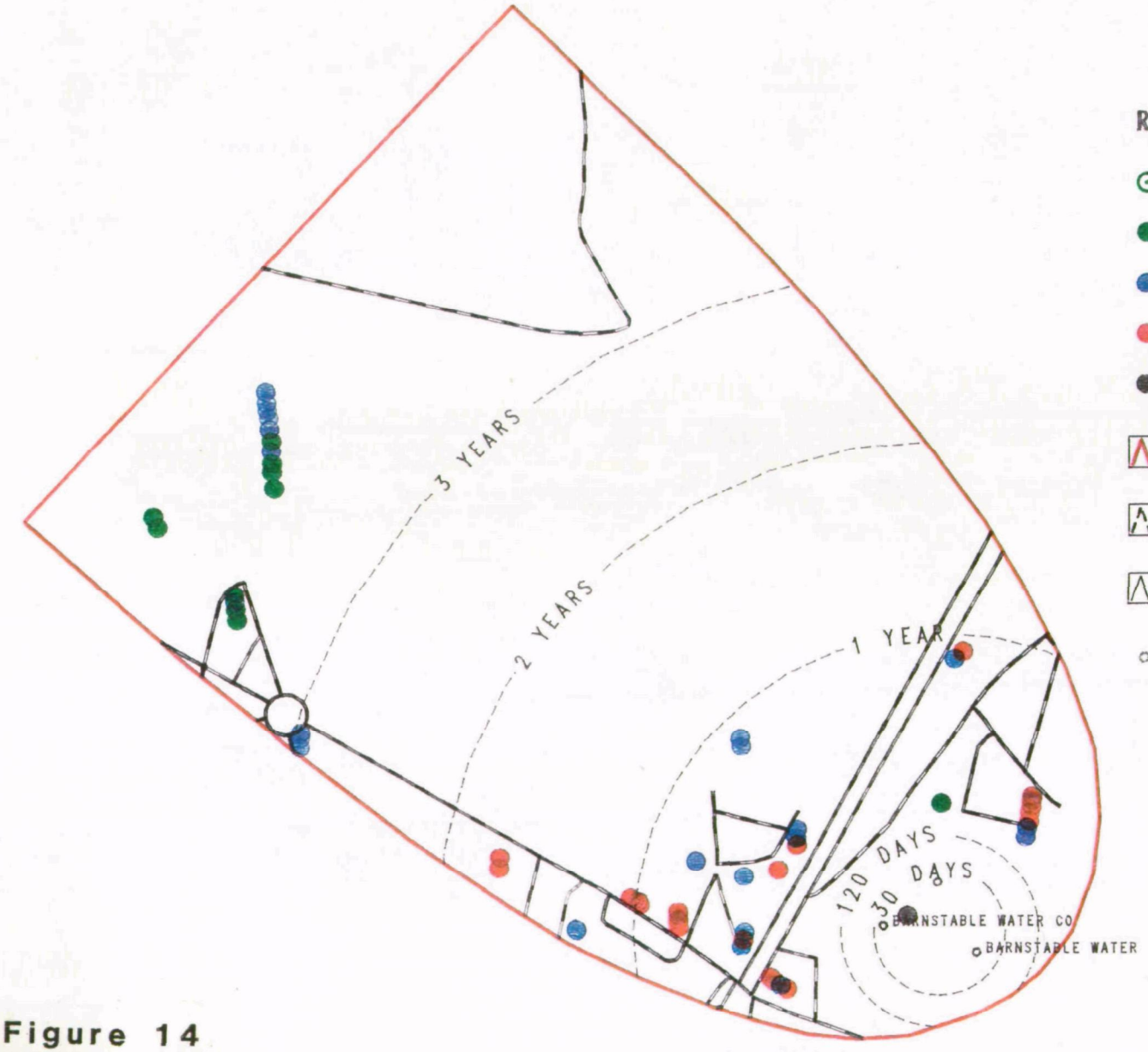
LOW ——— HIGH

- X - Non-Contributing or Sewered
- G - Dry Goods Stores
- P - Gas Stations
- F - Offices
- E - Small Businesses
- S - Restaurants
- A - Residential
- U - Motels, and Condominiums
- H - WWTP, and Special Cases

- Zone of Contribution Boundary
- Town-Line
- Public Water-Supply Wells

Figure 13

Assessing Risk to Ground-Water Quality At Public Water-Supply Sites From Underground Storage Tanks



EXPLANATION

RELATIVE RISK

- LOW RISK (0-20)
- LOW-MED RISK (21-40)
- MEDIUM RISK (41-60)
- MED-HIGH RISK (61-80)
- HIGH RISK (81-100)

- Maher Diesel #2 Zone of Contribution
- Groundwater Time-of-Travel Limits
- Major Roads
- Maher Diesel #2 Wells

Figure 14

Risk Ranking for Each Tank Characteristic and Total Risk For Each Tank

Data as of January, 1987

ID	DISTANCE	AGE	TANK MATERIAL	SIZE	CONTENT	URBANIZATION	RISK
LOW-MED RISK							
41	0	0	0	5	0	4	31
144	0	0	0	3	1	5	31
145	0	0	0	3	1	5	31
134	3	0	0	1	0	5	31
44	0	0	0	4	2	4	34
45	0	0	0	4	2	4	34
78	0	0	0	3	2	5	34
79	0	1	0	2	2	5	34
43	0	4	2	1	0	4	37
76	0	0	0	4	2	5	37
MEDIUM RISK							
165	2	2	2	1	0	5	41
77	0	0	2	4	2	5	44
128	3	1	2	2	0	5	44
36	0	2	2	5	1	4	48
42	0	4	2	2	2	4	48
179	3	3	2	1	0	5	48
186	3	3	2	1	0	5	48
163	3	2	2	1	0	6	48
37	0	4	2	4	1	4	51
39	0	4	2	3	2	4	51
40	0	4	2	3	2	4	51
80	1	3	0	3	2	6	51
121	3	1	2	4	1	4	51
81	1	3	0	3	2	6	51
122	3	1	2	4	1	4	51
82	1	3	0	3	2	6	51
180	3	3	2	1	1	5	51
184	3	1	2	2	2	5	51
38	0	4	2	4	2	4	55
129	3	0	2	1	5	5	55
183	3	3	0	3	2	5	55
50	3	3	2	4	0	5	58
160	3	3	2	2	2	5	58
MED-HIGH RISK							
123	3	3	2	5	0	5	62
124	3	3	2	5	0	5	62
125	3	3	2	3	2	5	62
126	3	3	2	3	2	5	62
182	3	3	2	3	2	5	62
152	2	4	2	2	2	6	62
153	2	4	2	2	2	6	62
156	3	1	2	4	2	6	62
157	3	1	2	4	2	6	62
158	3	1	2	4	2	6	62
159	3	1	2	4	2	6	62
185	3	5	2	1	2	5	62
162	3	2	2	3	2	6	62
49	3	3	2	4	2	5	65
127	3	3	2	4	2	5	65
154	3	4	2	2	2	6	65
155	3	4	2	2	2	6	65
161	3	2	2	4	2	6	65
164	3	3	2	3	2	6	65
181	3	3	2	2	5	5	68
118	2	3	2	5	2	6	68
119	2	3	2	5	2	6	68
HIGH RISK							
187	5	3	2	4	5	5	82

DISTANCE (Distance in feet from nearest public-supply well)	RANK
>4400	0
3251-4400	1
1976-3250	2
639-1975	3
426-638	4

TANK MATERIAL	RANK
Fiberglass	0
Double-Wall Steel	1
Steel	2
Concrete	3

AGE(Years)	RANK
0-4	0
5-9	1
10-14	2
15-20	3
21-25	4
26-30	5
Greater than or equal 30	6

SIZE(gallons)	RANK
<1000	1
1000-4999	2
5000-9999	3
10,000-19,999	4
Greater than or equal 20,000	5

CONTENT	RANK
Fuel Oil, #2 Fuel Oil, Heating Oil, New Oil, Empty	0
Aviation Gas, Kerosene	1
Diesel Oil, Gasoline	2
Waste Oil, Used Oil, Gear Oil	5

URBANIZATION (Zoning of the parcel that UST lies in)	RANK
Residential	0
Business Residential, Professional Residential	1
Limited Industrial, Urban Business	3
Industrial	4
Business	5
Highway Business	6

MAP NOTES: This illustration presents the results of one type of a multicriteria evaluation method to estimate the risk to ground-water quality at a public water-supply well from underground storage tanks. In an automated procedure, the range of values for six characteristics of each tank located within the zone of contribution to a well are ranked and then added to determine the relative risk of the tank. The data for this demonstration in the Barnstable ZOC were compiled in January 1987 by the Cape Cod Aquifer Management Project (CCAMP). This analysis is one of six demonstration scenarios prepared by the CCAMP-GIS project.

POTENTIAL RISK TO PUBLIC-SUPPLY WELLS FROM LANDFILLS, CAPE COD

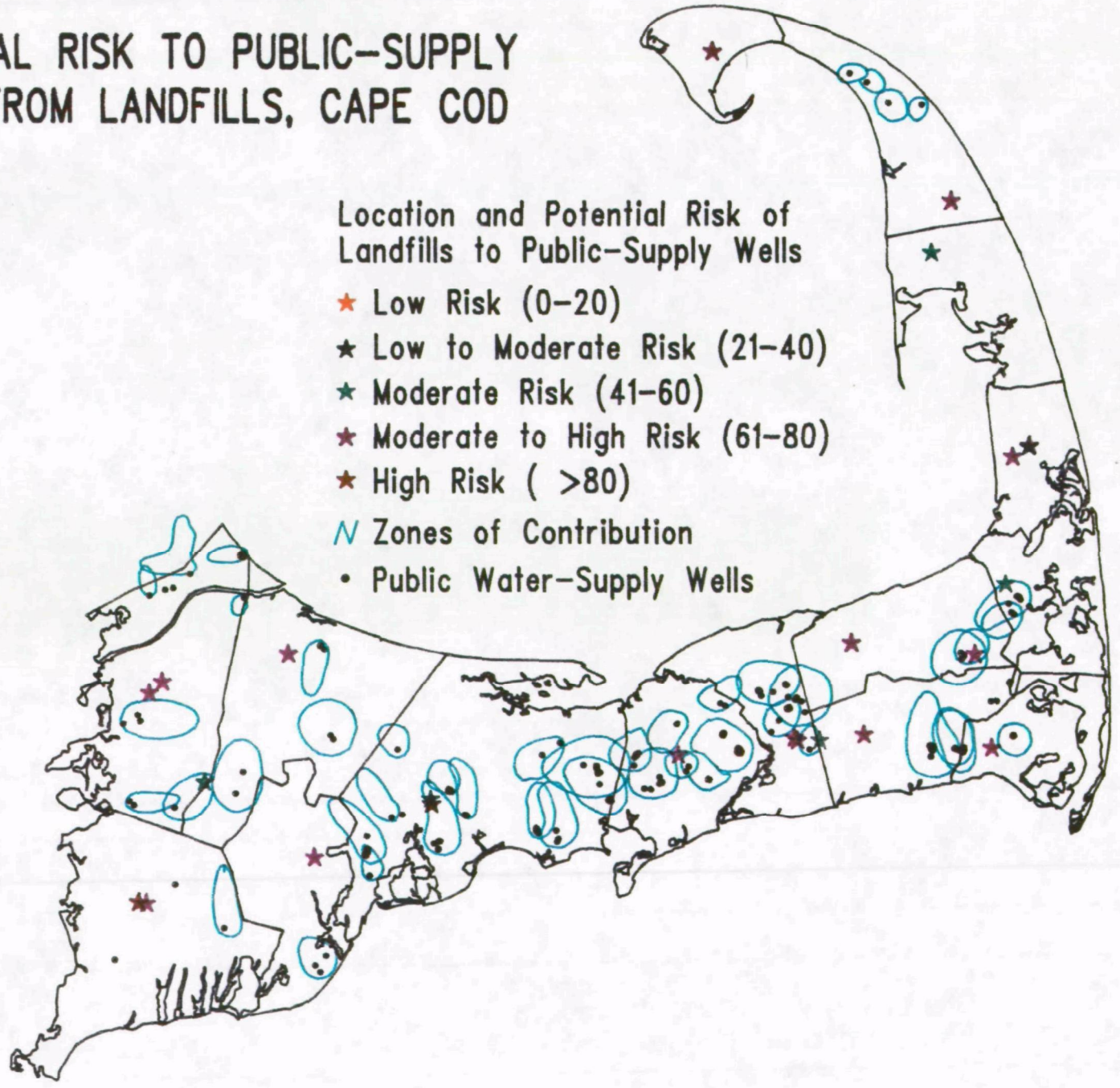


Figure 15

CRITERIA FOR RANKING LANDFILLS

DISTANCE (ft)	RANK
Less than or equal to 400	5
401-1000	4
1001-2640	3
2641-5280	2
Greater than or equal to 5281	1

Distance 1 - Measured only for landfills that fall inside a ZOC
- Distance is to the nearest well of that ZOC
- WEIGHTING FACTOR = 12

Distance 2 - For all landfills , the distance to the nearest well (if a landfill falls inside a ZOC exclude all wells inside that ZOC)
- WEIGHTING FACTOR = 3

THICKNESS/NATURE OF UNCONSOLIDATED MATERIAL	RANK
LEGRAND SCORE	
8-9	5
7	4
6	3
4-5	2
2-3	1
0-1	0
WEIGHTING FACTOR = 8	

SIZE (acres)	RANK
>50	5
21-50	4
11-20	3
6-10	2
Less than or equal to 5	1
WEIGHTING FACTOR = 8	

GRADIENT	RANK
>2% in anticipated direction of flow	3
<2% in anticipated direction of flow	2
Flat or away from anticipated direction of flow	1
Away from public water supply	0
WEIGHTING FACTOR = 4	

DEPTH TO WATER-TABLE (FT)	RANK
Less than or equal to 2	5
3-8	4
9-15	3
16-25	2
26-35	1
Greater than or equal to 36	0
WEIGHTING FACTOR = 6	

LINER	RANK
present	0
not present	5
WEIGHTING FACTOR = 4	

LEACHATE COLLECTION SYSTEM	RANK
present	0
not present	5
WEIGHTING FACTOR = 4	

Ranking of Landfill Characteristics and Calculated Total Risk

ID	NAME	DISTANCE 1	DISTANCE 2	DEPTH	GRADIENT	THICKNESS	ACRES	LINER	LEACHATE COLLECTION	RISK	
LOW RISK:		No Landfills in this category									
LOW TO MODERATE RISK:		No Landfills in this category									
MODERATE RISK:											
882	Wellfleet	0	1	5	3	2	2	0	5	56.00	
245	Eastham	0	1	4	2	2	2	0	5	57.00	
MODERATE TO HIGH RISK:											
1,000	Sandwich Stump	1	1	0	0	0	2	0	0	24.00	*
55	Cape Resources	1	2	0	0	0	2	5	5	48.00	*
349	Orr	2	1	0	0	0	1	5	5	52.00	*
184	Otis	1	1	0	0	0	5	5	5	55.00	*
820	Orleans	2	1	4	2	2	3	5	5	58.00	*
300	Blacksmith	0	1	0	0	0	1	5	5	62.00	
718	Sandwich	0	1	4	2	2	2	5	5	63.00	
833	Truro	0	1	2	2	4	2	5	5	65.00	
246	Nickerson Site	0	1	4	3	2	2	5	5	65.00	
200	Meshpee	0	1	2	3	5	3	0	0	67.00	
247	Erickson Site	0	1	0	0	0	2	5	5	68.00	
115	Brewster	0	1	2	3	4	2	5	5	68.00	
102	Bourne	0	2	0	0	0	2	5	5	72.00	
105	Bourne	0	1	0	0	0	3	5	5	73.00	
348	Harwich	0	1	2	2	5	4	5	5	75.00	
159	Chatham	0	2	2	2	5	3	5	5	75.00	
214	Dennis	0	2	0	0	0	3	5	5	77.00	
213	Dennis	0	2	3	2	5	3	5	5	78.00	
689	Provincetown	0	1	4	3	4	4	5	5	80.00	
HIGH RISK:											
116	Maye	3	3	0	0	0	2	5	5	68.00	**
954	Yarmouth	3	2	3	2	5	5	5	5	77.00	**
280	Falmouth	0	1	3	3	5	5	5	5	84.00	
54	Barnstable	1	2	4	3	5	5	5	5	87.00	

Special Conditions for landfills that fall inside a ZOC

** Landfills inside a ZOC and within 1/2 mile of that ZOC's wells are automatically put in the HIGH risk category.

* Landfills inside a ZOC and farther than 1/2 mile from that ZOC's wells are automatically put in the MODERATE-TO-HIGH risk category.

ZONES OF CONTRIBUTION AND HALF MILE BUFFERS AROUND PUBLIC SUPPLY WELLS

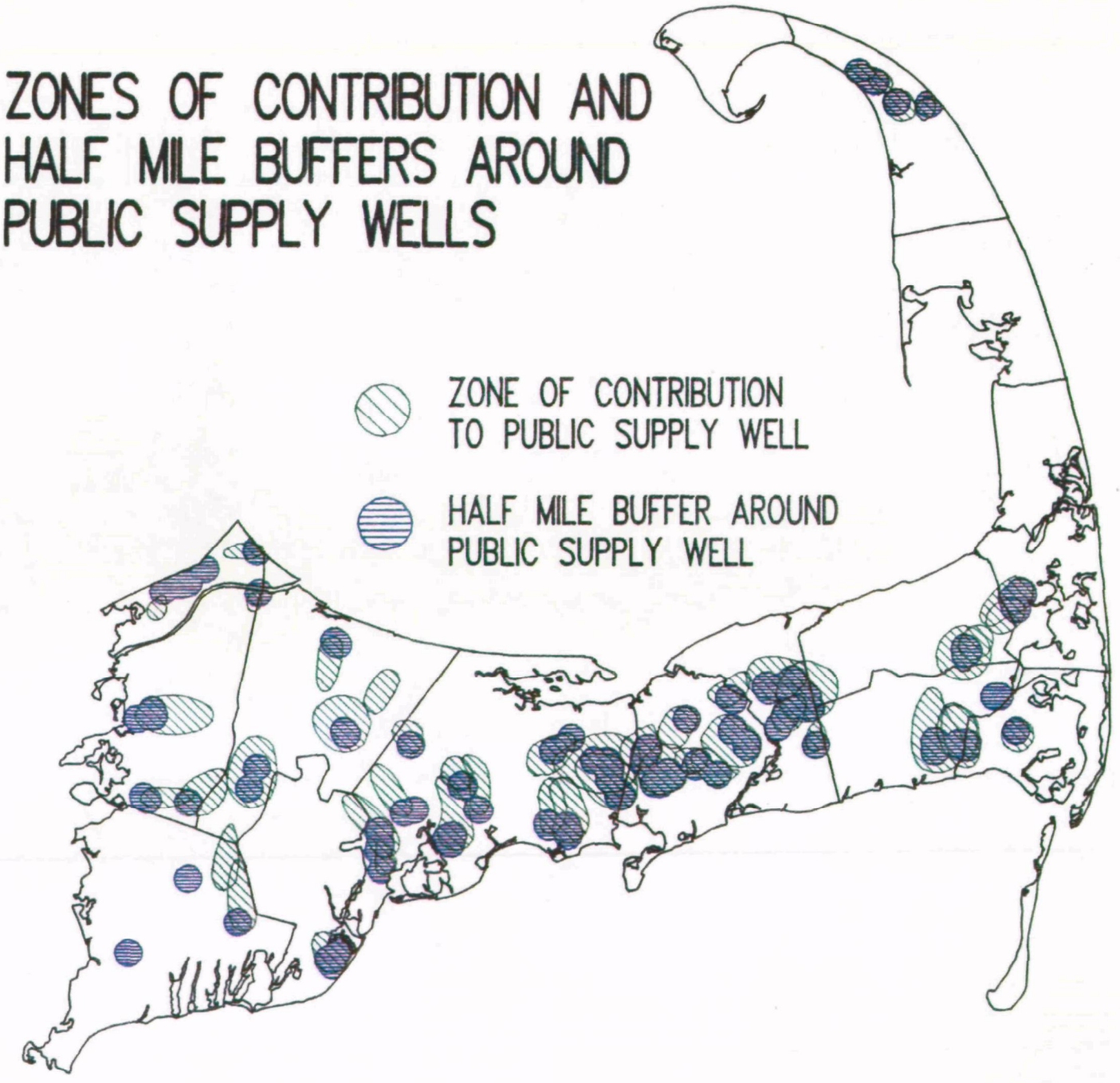


Figure 16