Waste Disposal
Effects of Sanitary Disposal Systems on Groundwater and Basic Economics of Sewer System Construction Costs Alternatives vs. Regional Installations

Prepared by Town of Old Lyme, CT Health Department
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DRAFT

A Simplified Economic Model Comparing Cost of a Regional and Local Alternative Methods of Sewage Disposal in Old Lyme, CT

A review has been completed by the Town of Old Lyme Health Department to compare a regional solution versus an alternative solution of sewage disposal in the coastal beach areas of Old Lyme, CT. The "Study Area" is defined in the report by Woodard & Curran issued December, 2014.

STUDY AREA

The Study Area, shown in Figure ES-1, comprises the unsewered beach communities and neighborhoods south of and along Route 156, between the previously sewered Point-O-Woods neighborhood to the east, and the White Sand Beach neighborhood to the west. On-site wastewater systems in the Study Area have been problematic for several decades, as a result of many combinations of factors including aging systems, poorly draining soils, soils that excessively drain with tidal movements, shallow groundwater, small lots, and excessive development density. Based upon the results of individual wastewater planning efforts by several of the chartered beach associations, it is clear that significant on-site septic system challenges and pollution problems exist in the Study Area. Past planning documents recommended that centralized solutions with off-site treatment and disposal are needed due to those documented wastewater disposal limitations.

This will be referred to as the Study Area in this narrative.

The Town of Old Lyme, Connecticut "Study Area" is presently experiencing moderate growth in population and full time housing density. The result of the increase in full time house density is impacting conventional sewage disposal systems and impacting groundwater quality resources for domestic water consumption in the "Study Area". The net result of the pollution from the sanitary disposal systems has resulted in the installation of water service to the "Study Area" to provide potable water to residents. Water is now available in the "Study Area"; however, the groundwater continues to be polluted by several different mechanisms of pollution transfer by the following:

1. "Cesspools" which contain organic solids, but are slow in digesting bacteria and viruses, and chemicals due to anaerobic oxidation conditions in the structure.

2. Sanitary disposal systems undersized producing ineffective digestion of nitrate products in effluent discharge.

3. Unknown broken sanitary disposal system components such as pipes and septic tanks leaking raw sewage into the underlying aquifer.

4. The existence of a high groundwater table +/- 2 feet below ground elevation surface, producing a shallow dry soil horizon for attenuation and absorption of pollutants before coming in contact with the groundwater aquifer in the "Study Area".

The net result of this untreated sewage reaching the groundwater aquifer has placed the "Study Area" under abatement orders by the DEEP Water Resource Unit. Presently consent orders to abate the pollution through the use of sewers to dwellings have been signed by Miami Beach Association, Old Colony Beach Club Association and Old Lyme Shores Beach Association.

The associations plan to send the effluent to the New London sewage treatment plant in cooperation with other regional town WPCAs. Presently, Point O' Woods has been sewered and is sending effluent to the New London sewage treatment plant with cooperation of East Lyme and Waterford.

The cost of sending sewage through a regional sewage treatment plant versus constructing an alternative plant in Old Lyme, Connecticut are well documented by engineering studies completed by Fuss & O'Neill in 2010-2011 and Woodard & Curran December 14, 2014. Summaries are provided in the appendix of this report.

A simple graphic economic model is proposed by the Town of Old Lyme Health Department exhibiting the cost of an onsite small town sewage treatment plant in comparison to a large regional plant serving many municipalities. The graphic is a "Life use" diagram of maintenance and replacement values of the two sewage plants. The numbers are "ballpark" cost numbers used frequently when preparing initial cost estimates for construction projects. The chart is summarized as follows:

Independent Town Sewage Treatment Plant

1. Initial cost to build $8,000,000 for new plant. Cost to the Town with a 30% grant - $5,600,000.

2. Life replacement in 20 years all components. At 15 year mark, replacement parts to be phased in to reconstruct by year 20.

3. Total retrofit $6,000,000. Cost to the Town with a 30% grant - $5,880,000
$5,880,000/1 town = Cost $5,880,000 to the Town.

Regional Sewage Treatment Plant

1. Retrofit cost from previous cycle $18,000,000

2. Town signs in at year "0".

3. Life replacement of plant is 50 years with retrofits beginning in year 45 to meet 50 year replacement mark.

4. Replacement cost $15,000,000
   Therefore, $15,000,000/5 municipal towns or agencies - $3,000,000 contribution by each town - $3,000,000 < $5,880,000

5. In summary - 45 years Regional Plant
   -15 years Local Plant
   30 years of deferred cost to accumulate money for the retrofit at 40 years for a regional plant

The Town of Old Lyme Health Department is presenting this very simplified economic narrow view of expenditures. The review does not take into account natural disasters. fluctuations in the financial market or government grants for replacement construction. The model outlines a regional solution is more economical than a local plant. In summary, as stated in the Fuss & O'Neill report and the Woodard & Curran study, the regional alternative for sewage disposal is more cost effective than the local alternative plan for sewage disposal.

Attachments:
Fuss & O'Neill Report - 2010-2011
Woodard & Curran Report - December 2014
Future Connecticut Water Company Expansion
Graph of Cost Replacement

Submitted by,

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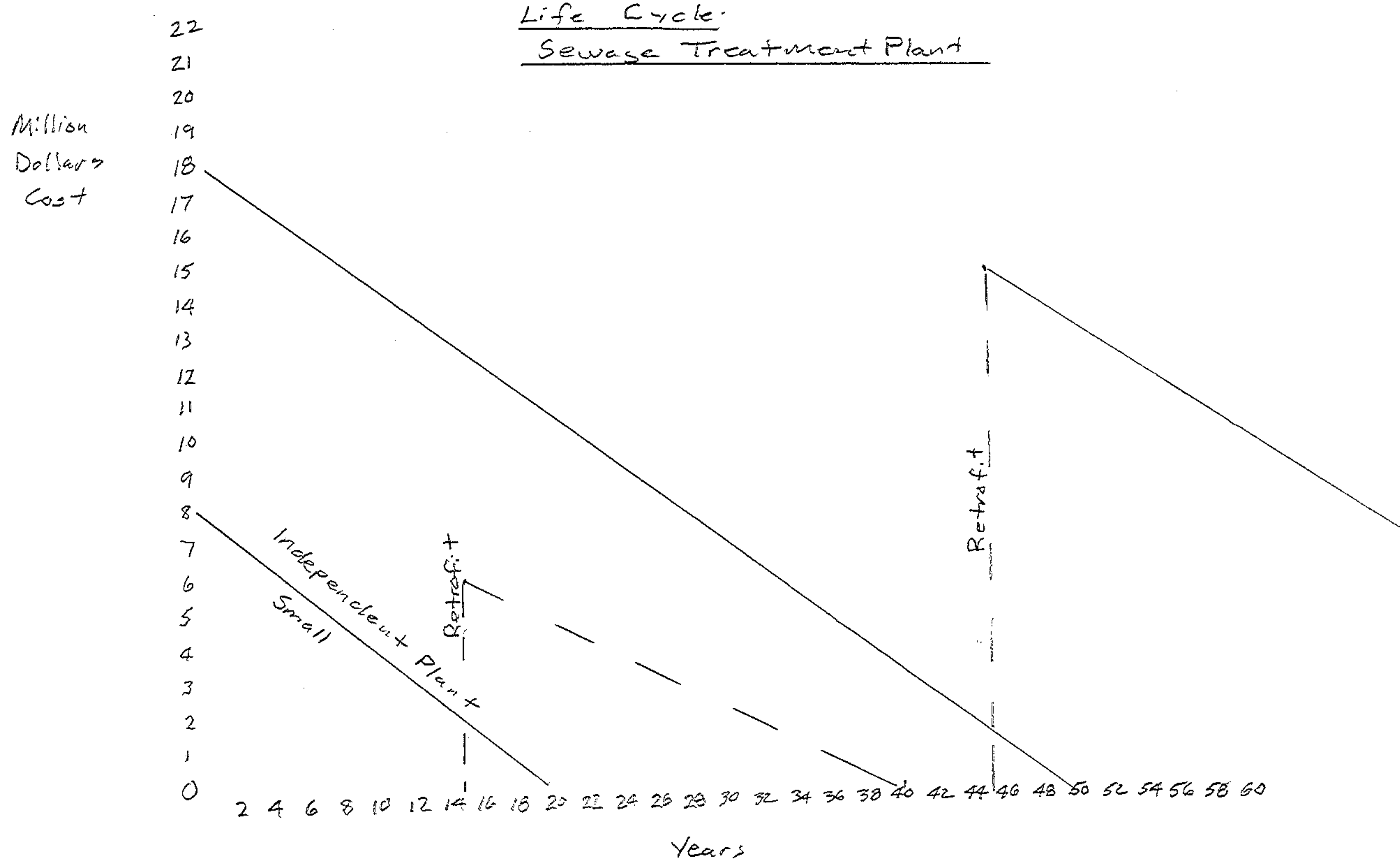
Sanitarian, Town of Old Lyme, CT
Health Department

March 18, 2015

Life Cycle
Sewage Treatment Plant



Replacement Start 15 years
6 Million / 1 town = 6 million Dollars

Replacement Start 45 years
15 million / 5 Agencies = 3 million each Dollars

The Centralized Sewer Alternatives have the lowest annual O&M costs because the wastewater treatment and disposal costs are split among the numerous parcels connected to the New London Wastewater Treatment Plant. This plant is currently being evaluated for re-rating to provide increased capacity for the upstream communities. The Decentralized Management alternative includes a significant annual operation and maintenance cost because the systems must be monitored, tested, and reported upon regularly to comply with the system design and DEEP wastewater disposal regulations. The Small Community System costs include operation and maintenance of a treatment plant and groundwater testing down gradient of a community leaching system.

Table 1-2: Summary of Annual O&M Costs

Wastewater Management Method	Collection System Type	Order of Magnitude Annual O&M Cost	
		-30%	50%
Conventional Septic Systems	None	N/A	N/A
Decentralized Management	None	$196,000	$420,000
Small Community System	Gravity Sewer	$166,000	$356,000
	Low Pressure Sewer	$168,000	$360,000
Centralized Sewer	Gravity Sewer	$86,000	$185,000
	Low Pressure Sewer	$87,000	$187,000

1.9.4 Summary of Life Cycle Costs

The summary of life cycle costs for Old Lyme Shores Beach Association is presented in Table 1-3. It compares all of the alternatives based on an annual project cost by apportioning the construction cost over 20 years at 2% interest, with addition of the annual O&M costs. The Small Community System has the highest life cycle cost followed by Decentralized Management. Centralized Sewers are the lowest life cycle cost for the residents of OLSBA.

Table 1-3: Summary of Life Cycle Costs

Wastewater Management Method	Collection System Type	Order of Magnitude 20 Year Annual Life Cycle Cost	
		-30%	50%
Conventional Septic Systems	None	N/A	N/A
Decentralized Management	None	$3,500	$5,800
Small Community System	Gravity Sewer	$3,900	$6,900
	Low Pressure Sewer	$4,000	$7,100
Centralized Sewer	Gravity Sewer	$1,800	$4,000
	Low Pressure Sewer	$1,900	$4,200

20 Year Annual Life Cycle Cost shown as a per parcel cost for 192 sewer connections.
Costs include 25% Clean Water Fund Grant monies for capital expenses.

A gravity sewer collection system with a central pump station carries a slightly lower capital cost but lower annual O&M cost because all of the system maintenance occurs at a single community pump station. This option is the preferred collection system method, but the pump station would require land acquisition, flood control measures, backup power, and approval from the local planning and zoning commission.

A low pressure sewer collection system has a lower capital cost but more expensive annual operations and maintenance (O&M) cost and slightly higher life cycle cost. Low pressure sewers also are generally not expandable to convey flows from surrounding areas.

Cost savings for this alternative may be achieved by connecting to the existing Point O' Woods central pump station, instead of constructing a separate force main along Route 156 to East Lyme. The Point O' Woods pump station would require capacity upgrades including larger pumps, new control equipment, and a potential generator upgrade.

1.10 Cost Sharing with Old Colony

To further reduce the overall capital costs, cost sharing with neighboring beach associations for the transmission pipe from the shore line area to the sewer connection to the east should be considered. Dividing the cost of a force main with Old Colony and/or Miami Beach has the potential for significant savings. Table 1-4 summarizes the cost savings of sharing the Capital Cost with Old Colony Beach Association.

Table 1-4: Summary of Capital Costs (Cost Sharing with Old Colony)

Wastewater Management Method	Collection System Type	Order of Magnitude Opinion of Capital Cost -30%	50%
Conventional Septic Systems (No Cost Sharing)	None	N/A	N/A
Decentralized Management (No Cost Sharing)	None	$6,300,000	$13,600,000
Small Community System (No Cost Sharing)	Gravity Sewer	$8,200,000	$17,700,000
	Low Pressure Sewer	$8,700,000	$18,500,000
Centralized Sewer	Gravity Sewer	$4,100,000	$9,400,000
	Low Pressure Sewer	$4,500,000	$10,300,000

Costs do not include 25% Clean Water Fund Grant monies for capital expenses.

The savings are estimated at $670,000 to $2,170,000. If cost sharing of a parallel force main to Point O' Woods pipe along Route 156 was also necessary, an additional savings of $830,000 to $1,800,000 is achievable.

Table 1-5: Summary of Life Cycle Costs (Cost Sharing with Old Colony)

Wastewater Management Method	Collection System Type	Order of Magnitude Opinion of Capital Cost -30%	50%
Conventional Septic Systems (No Cost Sharing)	None	N/A	N/A
Decentralized Management (No Cost Sharing)	None	$3,500	$5,800
Small Community System (No Cost Sharing)	Gravity Sewer	$3,900	$6,900
	Low Pressure Sewer	$4,000	$7,100
Centralized Sewer	Gravity Sewer	$1,600	$3,000
	Low Pressure Sewer	$1,700	$3,300

Costs include 25% Clean Water Fund Grant monies for capital expenses.

Obtaining an off-road easement through a bird sanctuary east of Hatchetts Point Road also has the potential to reduce costs by avoiding the railroad crossing expenses and time delays which may be significant. This parcel deed is reportedly written to restrict use to conservation land which may prevent construction of a sewer transmission pipe across it. However, accommodations can be made to prevent further connection to the pipe by designating it as a transmission main. This alternative also would cross the tidal wetlands at the end of Three Mile River which may pose permitting challenges, although the natural diversity database review indicated sewer construction does not pose a risk to the local wildlife. Construction via directional drilling is a potential solution to mitigate disturbance in the tidal wetlands area.

Annual O&M costs savings may be realized by contracting annual centralized sewer system operations and maintenance for multiple (or all) of the shoreline beach communities with a single management company.

With the construction of a sewer collection system, an opportunity also exists to upgrade some of the existing utilities throughout the community. The public water system is an old, seasonal system that is inadequately sized for current water demands during the summer and installed above the frost elevation. In the winter, it is turned off and drained to prevent pipe freezing. Connecticut Water expressed an interest in making improvements to the water system if a sewer collection system was constructed throughout the neighborhood because the cost of surface restoration (e.g. pavement repair, grass seed, etc.) can be shared between the projects. A second opportunity could involve moving the existing overhead utilities such as electricity, telephone, and cable system to underground conduits.

1.11 Implementation of Recommended Wastewater Management Plan

The recommended plan should be coordinated to construct improvements in concert with roadway improvements or other public works projects in the vicinity, in addition to the priorities defined in the Needs Matrix. A proposed implementation schedule is presented in Table 1-6.

Table 1-6: Implementation Schedule of Recommended WW Management Plan

Action	Timeframe
Study and Recommend Wastewater Management Method	Completed
Public Hearing	November 2011
Submit Wastewater Facilities Plan for DEEP review, comment, and approval	December 2011
Negotiate Sewer Tie In to Point O' Woods	Fall 2011 – Fall 2012
Negotiate Cost Sharing with Old Colony and other shorefront communities	Fall 2011 – Fall 2012
Negotiate Sewer Capacity Reallocation from Dept. of Corrections	Fall 2011 – Fall 2012
Negotiate Sewer Discharge to East Lyme	Winter 2012 – Summer 2012
Design Centralized Sewer Extension	Summer 2012 – Spring 2013
Permit Detailed Design Plans	Spring 2013 – Winter 2013
Bid and Construct Centralized Sewer Extension	Spring 2014 – Fall 2016

In summary, construction of a centralized sewer system will provide an effective long-term wastewater management solution to the shoreline community and has the potential to improve the ground and surface water quality of the waters of the State of Connecticut. Implementation of the recommended plan includes significant efforts to negotiate with multiple project stakeholders and anticipated lengthy project permitting due to the various parties involved. The implementation schedule attempts to take these obstacles into account and estimates a bidding and construction to start during the winter of 2013.

1.12 CEPA Consistency

The Connecticut Environmental Policy Act (CEPA) provides a framework for policy and planning for administrative/programmatic actions and capital/operational investment decisions of state government.

These regulations:

- Address human resource needs and development,
- Balance economic growth with environmental protection and resource conservation concerns, and
- Coordinate the functional planning activities of state agencies to accomplish long-term effectiveness and economies in the expenditure of public funds.

CEPA requires state agencies to undertake a comprehensive evaluation of any application action that might significantly affect the environment. The paragraphs below describe the impacts to the environment of the recommended plan and the agency reviews which must be received prior to implementation of the plan.

1.12.1 Coastal Area Management Program Consistency

The recommended plan is generally expected to be consistent with the goals and requirements of the Coastal Area Management (CAM) Program. The sewer extension option to cross the

Acknowledgments

We would like to acknowledge the following people and entities for their direct significant contributions to this project and the development of this Report.

- Town of Old Lyme
  - Board of Selectman
    - Bonnie Reemsnyder, First Selectwoman
    - Mary Jo Nosal
    - Skip Sibley
  - Sanitarian – Sonia Marino
  - Health Department – Patti Myers
  - Administrative Support – Catherine Frank
- Old Lyme WPCA
  - Kurt Zemba, Chairman
  - Andrea Lombard
  - Dimitri Tolchinski
  - Donna Bednar
  - Douglas Wilkerson
  - Ernest Lorda
  - Frank Chan
  - Robert McCarthy
  - Richard Pendergast
  - Tom Risom
  - Chris Seery, Administrative Support
- WPCA Attorney Andrew Lord
- Beach Associations
  - Old Colony Beach Club Association
  - Old Lyme Shores Beach Club Association
  - Miami Beach Association
  - Hawks Nest Beach Association
  - Sound View Beach Association
  - White Sand Beach Association
  - F&O – Kurt Mailman
- Black Hall Golf Course
- Town of East Lyme
  - Paul Formica, First Selectman
  - Brad Kargl, Town Engineer
- Town of Waterford
  - Jim Barteli, Public Works
- Tali Soto, Chief Engineer
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  - Dennis Greci
  - Carlos Esguerra
  - George Hicks
  - Corinne Fitting
  - Mike Hart
  - Joe Wetteman
  - Ossie Inglese
  - Margot Ward

Executive Summary

BACKGROUND

Leadership within Old Lyme recognizes that the Town, the Water Pollution Control Authority (WPCA) and the public all play important roles in addressing environmental challenges within their community. The Town has proactively accepted the responsibility of developing a progressive solution to the existing wastewater management challenges along the Old Lyme coastline. This updated Coastal Wastewater Management Plan Report is a continuation and culmination of prior work that the Town and chartered beach associates have completed and serves as an important planning tool. This Report was developed through tremendous collaboration of multiple parties and presents a comprehensive wastewater solution for specific areas of Old Lyme. It also serves as a guide to navigating the implementation plan for the recommendations.

STUDY AREA

The Study Area, shown in Figure ES-1, comprises the unsewered beach communities and neighborhoods south of and along Route 156, between the previously sewered Point-O-Woods neighborhood to the east, and the White Sand Beach neighborhood to the west. On-site wastewater systems in the Study Area have been problematic for several decades, as a result of many combinations of factors including aging systems, poorly draining soils, soils that excessively drain with tidal movements, shallow groundwater, small lots, and excessive development density. Based upon the results of individual wastewater planning efforts by several of the chartered beach associations, it is clear that significant on-site septic system challenges and pollution problems exist in the Study Area. Past planning documents recommended that centralized solutions with off-site treatment and disposal are needed due to those documented wastewater disposal limitations.

PROJECT GOALS

In response to current on-site wastewater management limitations, recent Consent Orders, comments received from CT-DEEP in response to the Town's 2012 Preliminary Study, public input, and the desire for a common solution for the Old Lyme coastal neighborhoods, the Town of Old Lyme retained Woodard & Curran to perform detailed evaluations of local and regional wastewater management alternatives for the Study Area. This project, termed the Coastal Wastewater Management Plan, focuses on the balance of short-term and long-term wastewater management needs within the Study Area, while considering wastewater infrastructure (collection, treatment, disposal and reuse), operation and maintenance (O&M) costs, annual and lifecycle costs, as well as non-cost factors. Non-cost factors include capacity allocation, wastewater management goals, and implementation measures to support the Town's current character and desire to avoid future growth via sewer construction.

NEEDS ANLYSIS

The Study Area was divided into thirteen Sub-Areas, as shown in Figure ES-1. In order to evaluate and prioritize wastewater management needs for the thirteen Sub-Areas, a wastewater management needs analysis was conducted. Factors including lot size, soil permeability, density of development, nitrogen attenuation, coastal sea level rise, groundwater conditions, water supply and age of septic systems were used to prioritize wastewater management needs..

PROPOSED PROJECT AREA

The Sub-Areas with the greatest need for wastewater management solutions comprise the proposed High Needs Sub-Areas. Table ES-1 lists the six Sub-Areas identified as High Needs Sub-Areas, including estimated equivalent dwelling units (EDUs) and average daily flow for each Sub-Area. The High Needs Sub-Areas are also shown in Figure ES-2.

Table ES-1:High Needs Sub-Areas

Sub-Area ID	Association or Street Name	Number of Equivalent Dwelling Units (EDU)	Average Daily Flow (GPD)
5A	Miami Beach	236	51,025
5B	Hawks Nest Beach	269	57,299
6	Sound View Beach	229	45,493
7	Old Colony Beach Club	218	43,967
8	Old Lyme Shores Beach	206	43,625
MTA B	Miscellaneous Town Area B	41	9,077
	Total	1,199	250,487

ALTERNATIVES ANALYSIS

Wastewater management systems are comprised of infrastructure components that generally include collection, treatment, disposal, and sometimes reuse. Two different primary wastewater management alternatives (the Local Alternative and the Regional Alternative) were developed and evaluated as part of the Coastal Wastewater Management Plan. The primary distinction between the two alternatives is that the Regional Alternative is predicated on the use of the existing New London WPCF to treat wastewater from the Project Area Sub-Areas, and the Local Alternative relies upon the construction of a new treatment facility in Old Lyme, coupled with either local subsurface disposal and reuse, or a new surface water discharge permit for the Connecticut River.

Each wastewater management alternative was evaluated and the collection, treatment and disposal/reuse options were summarized and estimates of probable costs were developed. Table ES-2 summarizes the anticipated costs for the Local and Regional Alternatives for the Project Area.

Table ES-2:Anticipated Costs for Local and Regional Alternatives for Project Area

	Capital[1]			Annual O&M		
System Component	Local #1 Disposal/Reuse	Local #2 - CT River Discharge	Regional	Local #1 Disposal/Reuse	Local #2 - CT River Discharge	Regional
Collection	$23,529,000	$23,529,000	$29,952,000	$217,000	$217,000	$336,000
Treatment	$14,500,000	$14,500,000	$5,995,000	$532,000	$532,000	$76,000
Disposal	$12,800,000	$9,457,000	$0	N/A[2]	N/A[2]	N/A[2]
Totals	$50,829,000	$47,486,000	$35,947,000	$749,000	$749,000	$412,000

1. Local and Regional Costs based on gravity sewer collection systems for Project Area.

2. Annual Disposal and Reuse costs are included with Treatment O&M.

Relative to capital costs, the collection system costs for the Regional Alternative are significantly higher than those for the Local Alternatives. This is primarily because the Regional alternative includes pump station, force main and gravity sewer needs in East Lyme and Waterford that are triggered by the proposed connection. However, the anticipated treatment costs are much lower for the Regional Alternative than for the Local Alternatives, since new and costly treatment systems are not required for the Regional Alternative. Overall, the Regional Alternative is approximately $15M less than the Local Alternatives. However, there is greater potential for major deferred capital expenses for the Regional Alternatives. For example, New London has not developed a capital plan for their WPCF, which would identify long term capital improvements for which Old Lyme would be required to contribute to in the future. The same can be said for the extent of future capital needs in East Lyme and Waterford, which would also require that Old Lyme contribute to these costs.

With regard to annual O&M costs, we estimate that the annual O&M costs for the Local Alternative are approximately $340,000 more expensive than that for the Regional Alternative. This cost differential could change depending in the extent of external contract operations services utilized by the Town and beaches. We also note that Old Lyme has less control over future escalations in annual O&M costs with the Regional Alternative.

There were several non-cost factors that were considered by the Town in this evaluation. These include:

- Implementation of New Utility: Both the Local and Regional Alternative included the establishment of a new wastewater utility, thus presenting unique implementation challenges. Initial years for a new utility can be difficult, as connections are being made, and systems are commissioned and connections are being made.
- Control of Flow Allocations: To ensure a successful project and meet the commitment to the new sewer users, the Town of Old Lyme will need to manage the allocation of sewer flows, capital costs, and annual costs. This will require active and continued participation from the Old Lyme Water Pollution Control Authority (WPCA) and an increased understanding of the various related factors.

RECOMMENDED PLAN

Despite the slightly higher annual O&M cost projections for the Regional Alternative, as well as the anticipated deferred capital costs associated with the Regional Alternative, the Regional Alternative capital cost projection is approximately $15M lower than the Local Alternatives for the Project area. This is predicated upon a cooperative approach between the Town and the chartered beach associations. This collaboration includes common pump station/force main sharing and sewering across/through municipal boundaries, which facilitates the maximization of cost sharing. If the Town and the chartered beaches decided to connect to New London independently using multiple individual pump stations and force mains, the costs for the Regional Alternative would be much higher. Therefore, based on the cooperative effort, as described, and endorsed by CT-DEEP, we recommend the Regional Alternative be implemented. Figure ES-2 shows the regional alternative for the Project Area.

Woodard & Curran performed a cost analysis on the Regional Alternative to determine the net annual cost to the property owners in the Project Area for both capital cost and debt service. Figure ES-3 summarizes the anticipated project appropriations for each Sub-Area (Town managed and chartered beach areas), excluding the grant funds (25%) anticipated from CT-DEEP.

IMPLEMENTATION PLAN

There are four major elements of the Implementation Plan for the Coastal Wastewater Management Project. These include:

1. management planning with the Beach Communities,
2. funding/finance considerations,
3. continued public outreach and participation, and
4. management of the schedule to complete the program.

Management Planning With the Beach Communities

The Town of Old Lyme and the Chartered Beach Communities have made tremendous progress in positioning the Coastal Wastewater Management Project for success. The parties have realized the power of collaboration and will realize significant cost savings through the implementation of a single unified program. Going forward, the stakeholders will need to continue to work together on the design elements of the project. The team will work collaboratively throughout the Project.

Funding/Finance Considerations

The representatives of the Project Area understand that the Coastal Wastewater Management Project will be self-funded, meaning that the users of the system will pay their pro-rata share of the project costs (on an EDU basis). The project will be implemented utilizing CT-DEEP Clean Water Funds. These funds reimburse the participant with a grant for 55% of planning costs, and 25% of design and construction costs. The Town of Old Lyme (Sub-Areas 5B, 6 and MTA-B) will appropriate funds for their respective share of the program while Miami Beach (Sub-Area 5A), Old Colony Beach (Sub-Area 7) and Old Lyme Shores (Sub-Area 8) have each already appropriated their respective shares.

Public Outreach & Participation

Public outreach and participation to date has been a key focus of the Town, the Old Lyme WPCA, and the chartered beaches. For example, the Town has had more than 30 public meetings and informational sessions on the project to date. Public input has already had a positive impact in shaping the recommended plan.

The Town and WPCA are committed to continuing to provide education and outreach opportunities as the Project is implemented. The current schedule of public outreach includes (but will not be limited to):

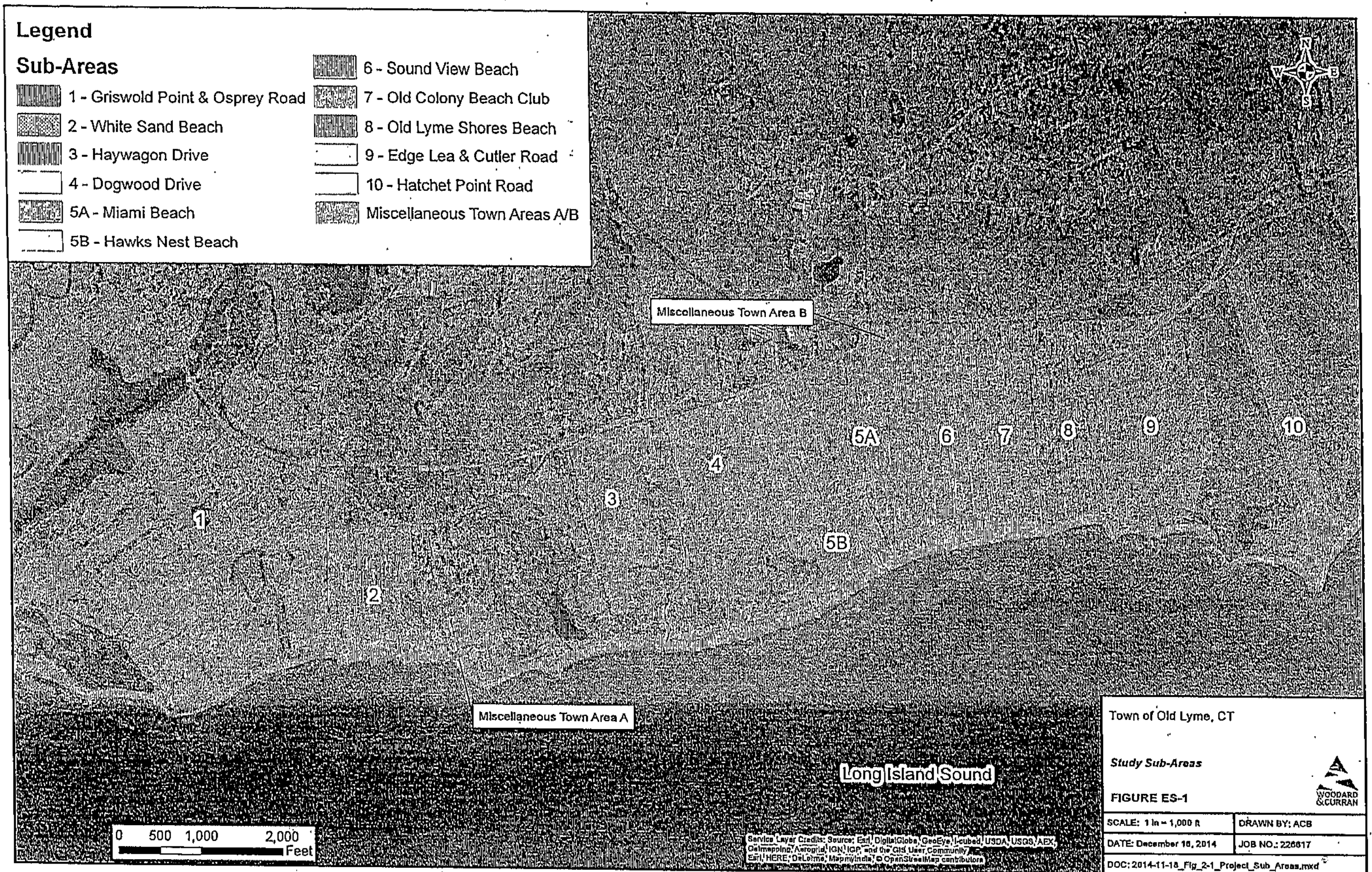
- Public Informational Meeting – Winter/Spring 2015
- Town Meeting/Referendum – Spring/Summer 2015
- Design Public Meeting – Summer/Fall 2015
- Construction Public Meeting – Spring/Summer 2016
- Public Ribbon Cutting – Summer 2019

Schedule to Complete the Program

Old Colony Beach Club and Old Lyme Shores Beach (Sub-Areas 7 and 8) have outstanding Consent Orders requiring completion of construction by June 30, 2016. While we believe that the Town's Regional Alternative can be implemented concurrently with the Beach Association projects, there will need to be an adjustment by CT-DEEP to the current Consent Order schedules.

We propose the following schedule milestones:

- Town Meeting (appropriation of project funds) – Spring/Summer 2015
- Design – Spring/Summer 2015 thru Spring 2016
- Construction – Spring/Summer 2016 thru Winter 2018
- Commissioning, start-up and integration – Winter 2018 thru Summer/Fall 2019


Legend
Sub-Areas
1 - Griswold Point & Osprey Road
2 - White Sand Beach
3 - Haywagon Drive
4 - Dogwood Drive
5A - Miami Beach
5B - Hawks Nest Beach
6 - Sound View Beach
7 - Old Colony Beach Club
8 - Old Lyme Shores Beach
9 - Edge Lea & Cutler Road
10 - Hatchet Point Road
Miscellaneous Town Areas A/B
Miscellaneous Town Area B
Miscellaneous Town Area A
Long Island Sound
1
2
3
4
5A
5B
6
7
8
9
10
N
S
E
W
0 500 1,000 2,000 Feet
Town of Old Lyme, CT
Study Sub-Areas
FIGURE ES-1
WOODARD & CURRAN
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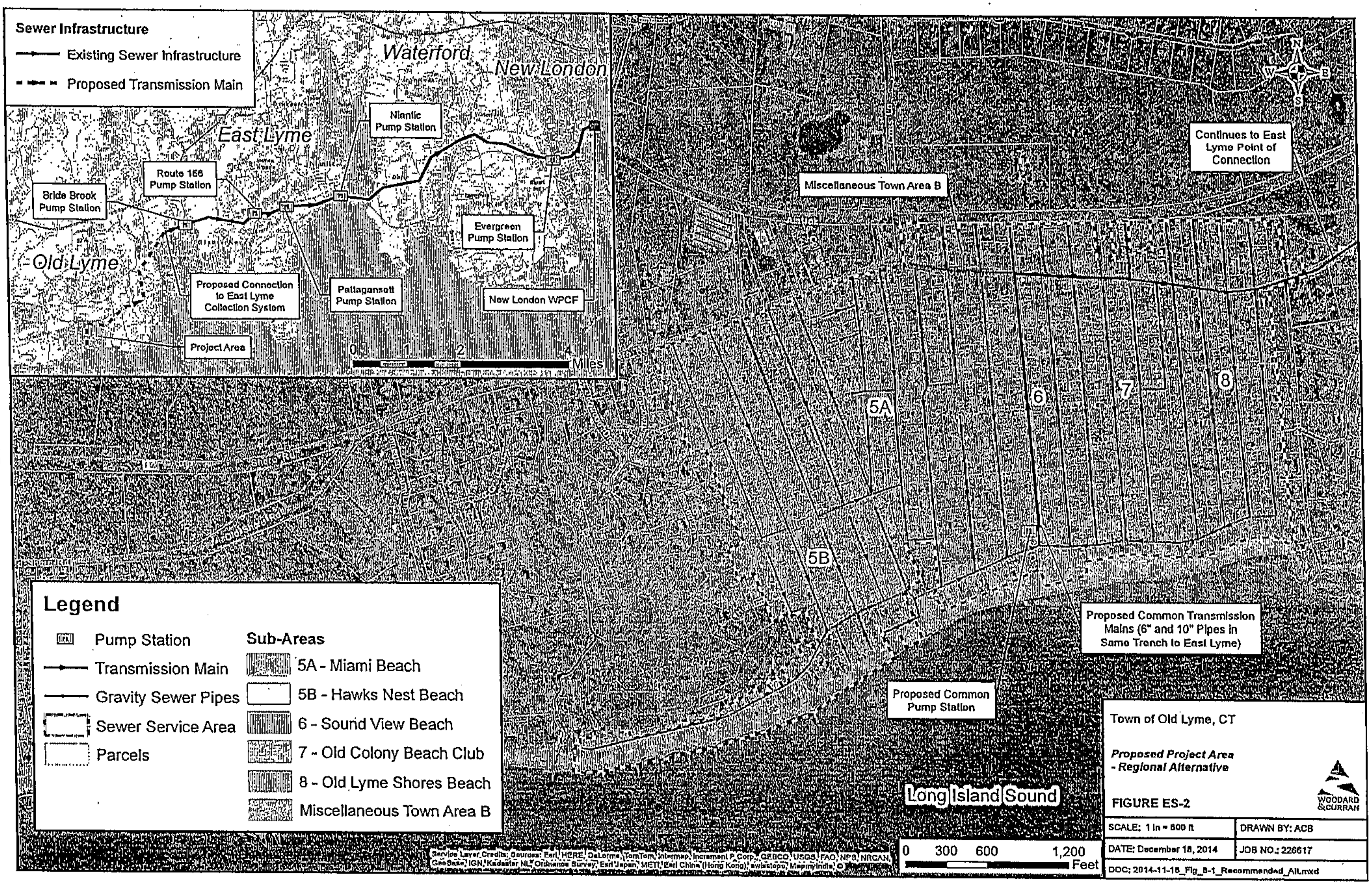
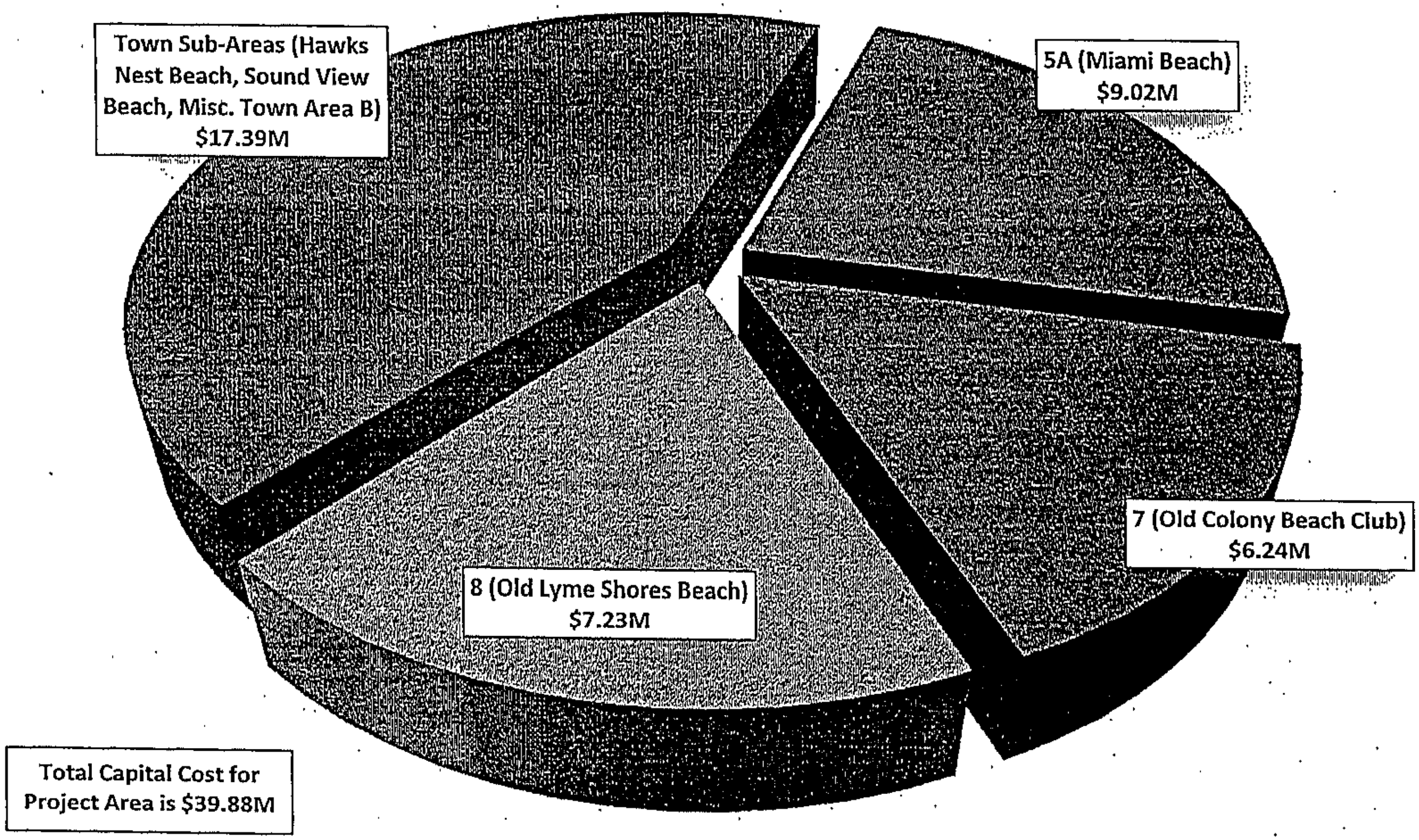

Sewer Infrastructure
Existing Sewer Infrastructure
Proposed Transmission Main
Waterford
New London
East Lyme
Old Lyme
Niantic Pump Station
Route 156 Pump Station
Bride Brook Pump Station
Evergreen Pump Station
Proposed Connection to East Lyme Collection System
Pattagansett Pump Station
New London WPCF
Project Area
0 1 2 4 Miles
Miscellaneous Town Area B
Continues to East Lyme Point of Connection
5A
5B
6
7
8
Proposed Common Transmission Mains (6" and 10" Pipes in Same Trench to East Lyme)
Proposed Common Pump Station
Long Island Sound
Legend
Pump Station
Transmission Main
Gravity Sewer Pipes
Sewer Service Area
Parcels
Sub-Areas
5A - Miami Beach
5B - Hawks Nest Beach
6 - Sound View Beach
7 - Old Colony Beach Club
8 - Old Lyme Shores Beach
Miscellaneous Town Area B
0 300 600 1,200 Feet
Town of Old Lyme, CT
Proposed Project Area - Regional Alternative
FIGURE ES-2
WOODARD &CURRAN
SCALE: 1 in = 600 ft
DRAWN BY: ACB
DATE: December 18, 2014
JOB NO.: 226617
DOC: 2014-11-18_Fig_8-1_Recommended_Alt.mxd

Figure ES-3: Summary of Anticipated Total Capital Cost Sharing (2017 Costs) Regional Alternative - Project Area



Addendum 1
Nitrogen Attenuation

In order to justify the use of a sewer to the beach areas, the capacity of the land to renovate pollutants discharged is required to be investigated to protect the needs and distribution areas to be sewered.

A typical small lot in the proposed sewer area was .10 of an acre with a three bedroom sanitary disposal system. The analysis was taken in four parts. Example 1 - Nitrogen Attenuation on Small Parcels Strong Sewage, Example 2 - Nitrogen Attenuation on Small Parcels Light Sewerage, Minimal Parcel Size for a 3 Bedroom Dwelling to Maintain 10mg/liter Nitrate Standard for Drinking Water at 40mg/liter Sewage Concentration of Nitrate, Pollutant Renovation - Pathogens, Viruses and Bacteria on Permeable Soils. Outcomes are tabulated on the sheets. In summary, the small land parcel of .10 acres cannot attenuate nitrates on site. The minimum lot size of permeable soil to attenuate nitrates on a parcel is .6 acres to obtain a nitrate concentration of 10mg/liter to drinking water standards. By observation, many of the lots in the proposed sewer areas are less than .6 acres with more than there bedroom dwellings. The land is essentially saturated to its capacity to attenuate pollution from the dwelling.

Additional Cost Data was copied out for review of maintenance and projected capital cost and projected schedule of implementation of the sewer project. The information is provided by the Town of Old Lyme Health Department as a planning tool for future land use practices in new housing or commercial projects.

Attachments:
Example 1 - Nitrogen Attenuation on Small Parcels Strong Sewage
Example 2 - Nitrogen Attenuation on Small Parcels Light Sewerage
Minimal Parcel Size for a 3 Bedroom Dwelling to Maintain 10mg/liter Nitrate Standard
Pollutant Renovation - Pathogens, Viruses and Bacteria on Permeable Soils
Fuss & O'Neill Regional Wastewater Map and Cost Data
RFP Engineering LLC Preliminary Opinion of Capital Costs

Submitted by,

John T. Sieviec M.S.R.S.

John T. Sieviec, M.S.R.S.
Sanitarian, Town of Old Lyme, CT
Health Department

March 24, 2015

J. Sievitz 3-24-15
Nitrogen Attenuation Example 1
on Small Parcels Strong Sewage

Example 1:

Lot Size 50' x 90' = 4,500 S.F. Lot Size

3 bedroom dwelling 3 x 150 gallon/day = 450 gallons/day

Nitrate Concentration 80 mg/l

Renovation in Tank 72 mg/l

Available Dilution Water .01 ft/sqft/day x .6 infiltration

= .006 ft/sqft/day

Convert 450 gallon/day to Liters day

450 gallons/day x 3.785 gl/l = 1703.25 liters/day

Rainfall for Dilution 4,500 S.F x .006 ft/sqft/day

= 27 cuft/day x 7.481 = 201.98 gallons

Gallons to Liter 201.98 gallons x 3.785 = 764.49 liters

Delivery to site 1703.25 x 72 mg/l = 122,634 mg

764.49 liters + 1703.25 liter = 2,467.74

Final Concentration

122,634 mg / 2,467.74 = 49.69 mg/liter

Drinking Water Standard is 10 mg/liter

49.69 mg/liter > 10 mg/liter

Discharge Nitrates Exceeds Drinking water limit of Nitrates 10 mg/liter

J. Sieviec 3-24-15
Nitrogen Attenuation Example 2
on Small Parcel

Light Sewage

Nitrate Concentration
40mg/l

Example 2

Lot Size: 50' x 90' = 4500 S.F.

3 bedroom dwelling 3 x 150 gallon/day = 450 gallon/day

Convert 450 gallon/day to Liters day

450 gallons x 3.785 liter/gallon = 1703.25 liter/day

Rainfall for Dilution 4,500 S.F. x .006 ft/sq ft/day =

27 cu ft/day x 7.481 gal/cfs = 201.98 gallon/day

Gallons to Liter 201.98 x 3.785 = 764.49 liters

Renovation in tank 36mg/liter

Delivery to Site 1703.25 liter x 36mg/l = 61,317 mg

Dilution 764.49 liters + 1703.25 liters = 2,467.74 liters

Final Concentration Nitrates:

61,317 mg / 2467.74 liter = 24.84 mg/l

24.84 mg/liter > 10 mg/liter

Discharge Nitrates Exceeds Drinking Water limit of Nitrate 10mg/liters

Minimum Parcel Size
for a 3 Bedroom Dwelling
to Maintain 10mg / liter
Nitrate Standard for
Drinking Water at 40mg/liter
Sewage Concentration of Nitrate

J. Sievier
Sheet 3 of 3
3-24-15

Reverse Calculations to Determine Minimum Lot Size to Keep Nitrate Concentration at the 10mg/liter Drinking Water Standard

From Previous Example <u>Light Sewage</u>

61317mg / x = 10mg/liter

61317mg (10mg/liter) = 613170

6131.70 − 1703.25 4,428.45 liter

4428.45 / 3.785 = 1,170 gallons/day

1,170gal / 7.481 gallon/cuft. = 156 cft/day

156 cft/day /.006 ft/sf./day = 26,066 S.F Area

26066 S.F / 43560 acre/SF = .598 acres

Approximately .6 acres Required

to obtain a Nitrate Concentration of 10 mg/liter Drinking water Standard for a 3 Bedroom Dwelling on a parcel

S.F = Square Feet
cft/day = Cubic Feet per day

J. Sievier
3-24-15
Sheet 1of1

Pollutant Renovation

Pathogens Viruses and Bateria

1) % Survival after 35 days <.01 unit/100ml

2) Groundwater Velocity V=ki/n
(Selected Average Perameters)

K = 2.5 x 10^-2 cm/sec = 70.8 ft/day Permeability

i = . (101-100)/100 = .01 ft day

n = Pourosity 35% (Davis & Cornwall)

V = 70.8 x .01 /.35 = 2.02 ft day

Distance for 21 Day Travel to Property Line

21 days x 2.02 ft/day = 42.42 ft

Distance for 35 Day Travel Renovation

35 day x 2.02 ft/day = 70.7 ft.

Travel Times for Different Velocities more Permeable Soils

Soils Increasing Perm.

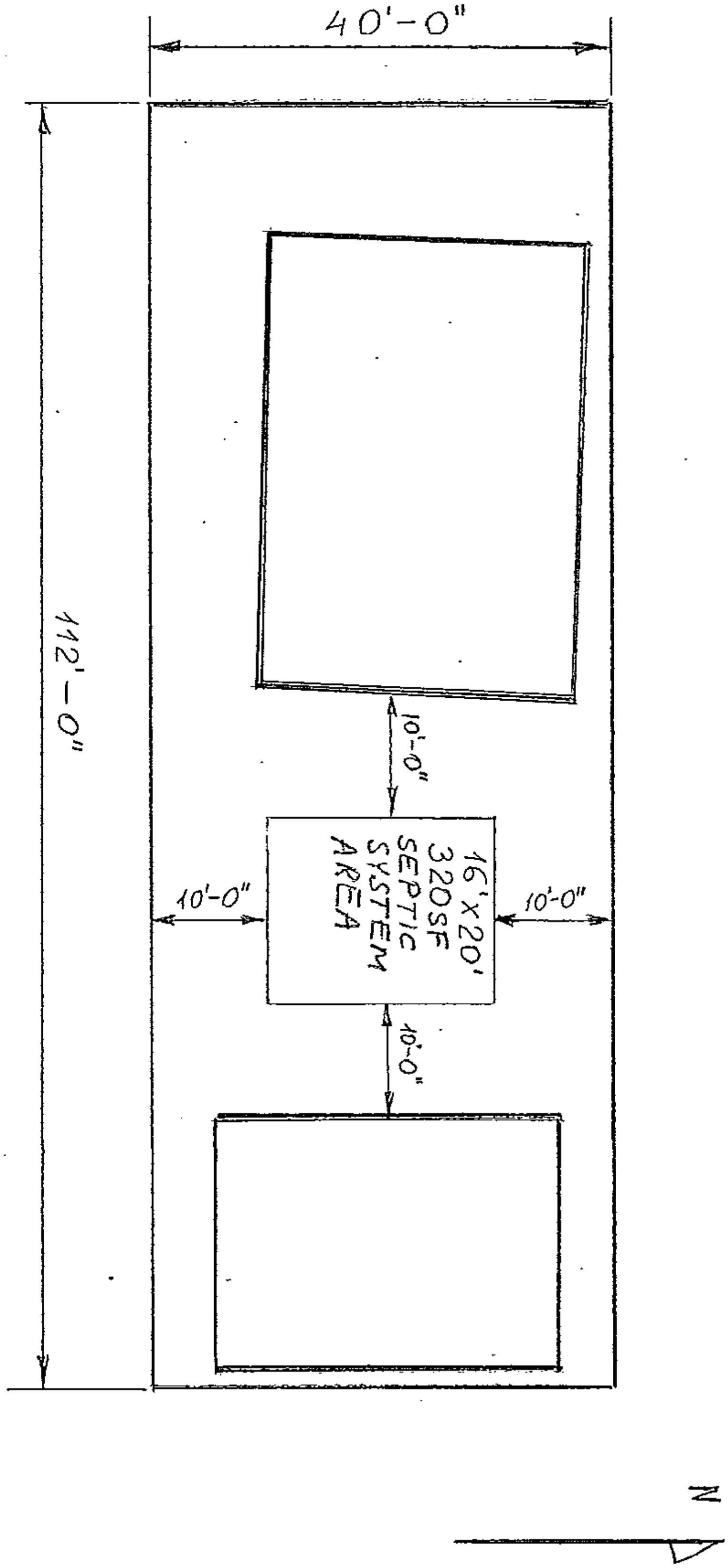
A. 21 days x 4.0 ft/day = 84 ft to Property Line
35 days x 4.0 ft /day = 140 ft Renovation

B. 21 days x 6.0 ft /day = 126 ft to Property Line
35 days x 6.0 ft./day = 210 ft Renovation

C. 21 days x 8.0 ft/day = 168 ft to Property Line
35 days x 8.0 ft/day = 280 ft Renovation

Addendum 2
Renovation of Pathogen, Viruses and Bacteria at White Sands Beach

White Sands Beach area, at present, has been removed from the list of areas to be sewered from the current proposed sewer construction. The area has been removed because some of the parcels can support an on site code complying sanitary disposal system, however, some of the smaller lots, as exhibited in Figure A, have limited area for any sanitary disposal system on site. The small size lots do not have enough area to dilute pollution form a leaching system. The following example is for renovation of pathogen, viruses and bacteria on a small lot.



OLD LYME, CT
SCALE 1/16" = 1'-0"

Renovation of Pathogen
Viruses and Bacteria on
a Small Lot .10 Ac

1) % Survival after 35 days <.01 unit /100ml

Velocity Formula

2) Groundwater Velocity = V   V = Ki/n

K = Soil Permeability cm/sec = 70.8 ft./day

i = Slope $\frac{101-100}{100}$ = .01 ft/day

n = Pourosity of Sand & Gravel 35% (Davis & Correal)

3) Velocity = V = 70.8 ft/day × .01/.35 2.02 ft/day

4) Distance for 35 day travel Renovation

35 days × 2.02 ft/day = 70.7 ft travel

5) Bacteria and Virus reduction requires 70.7 ft for die off

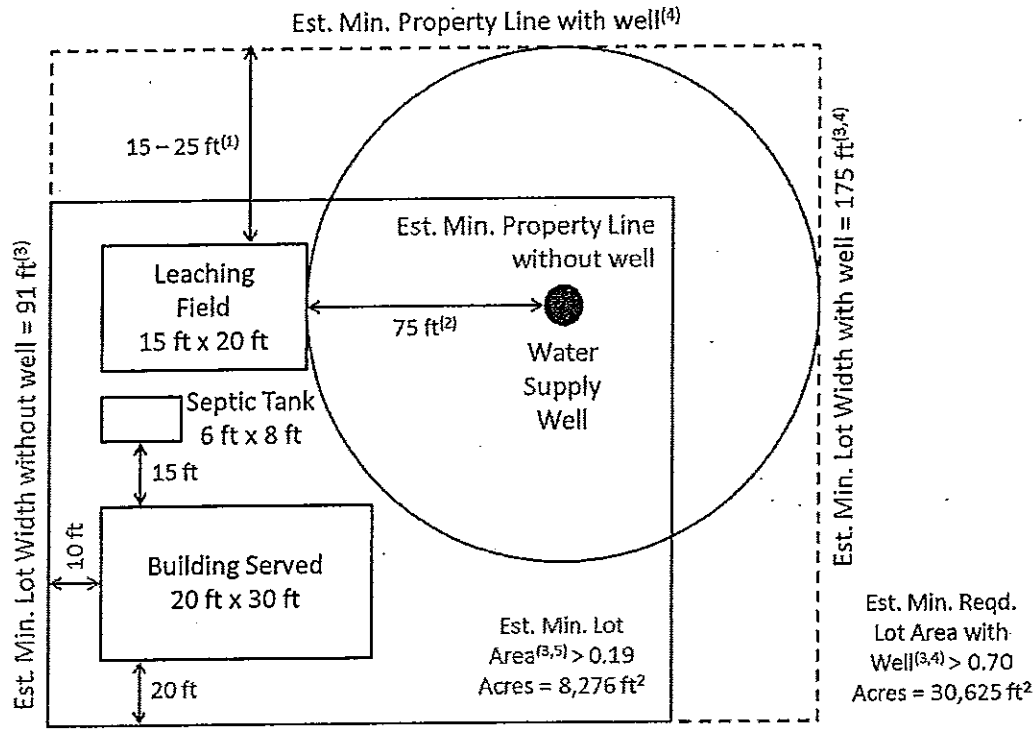
6) "Faster" permeabilities require more distance for die off. Soils "A", "B", "C"

Soil A	21 days × 4.0 ft/day	= 84 ft to Property Line
	35 days × 4.0 ft/day	= 140 ft to Renovate
Soil B	21 days × 6.0 ft/day.	= 126 ft to Property Line
	35 days × 6.0 ft/day	= 210 ft to Renovate
Soil C	21 days × 8.0 ft/day	= 168 ft to Property Line
	35 days × 8.0 ft/day	= 280 ft to Renovate

The smaller lots ie .10 Ac. will require additional monitoring for septic failures. The results of the monitoring may justify installation of sewers at a later date

Beach and Sound View Beach have lot areas smaller than 0.19 acres, suggesting that most likely these two Sub-Areas do not meet the minimum estimated required lot area with or without an onsite well. As shown in Table 2-4, houses in adjacent parcels also have a minimum separation distance of 15 feet from subsurface sewage disposal systems.

Figure 2-3: Estimated Minimum Subsurface Disposal System Setbacks for CT-DPH Compliance

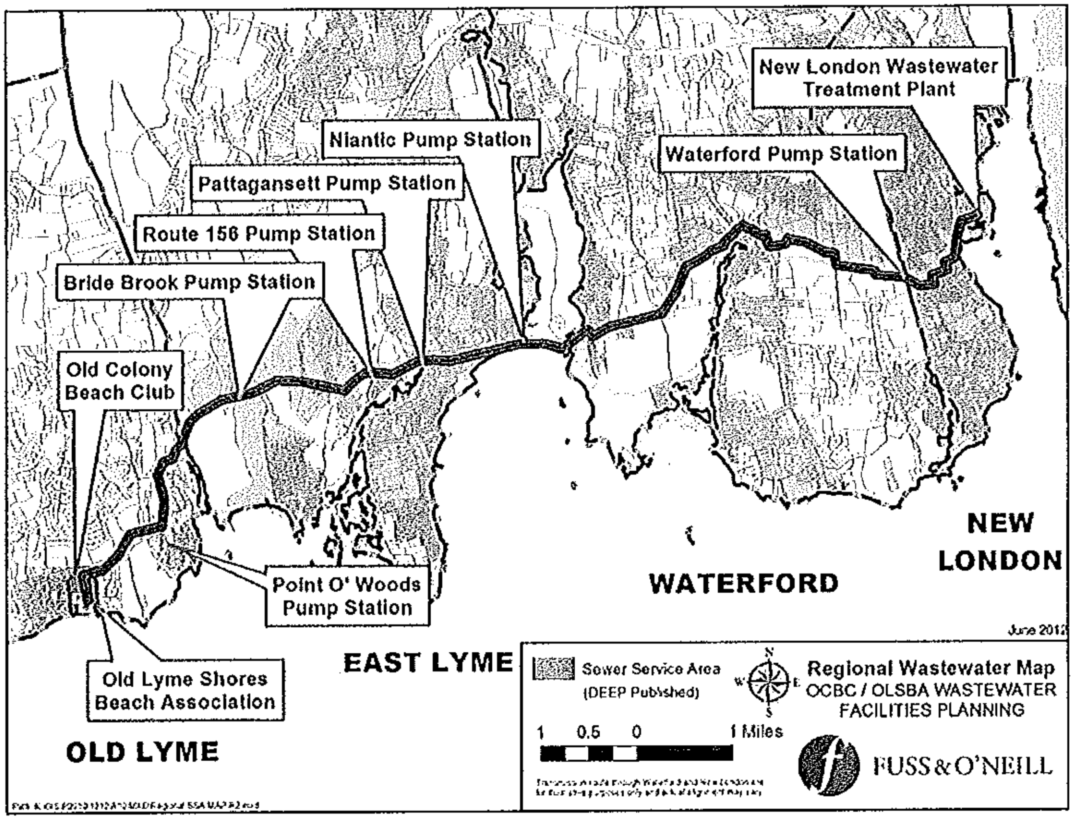


1. *15 ft if property line is upgradient or on sides of leaching field, 25 ft is downgradient.*
2. *75 ft for withdrawal rate of less than 10 gpm, 150 ft for 10 to 50 gpm, or 200 ft for greater than 50 gpm.*
3. *Assuming square lots.*
4. *Assuming minimum setbacks (75+75+15+10 = 175 ft).*
5. *Minimum lot size necessary for total nitrogen concentration at property line of less than 10 mg/L.*

Age of septic system construction were provided by the Town sanitarian for four Sub-Areas, including White Sand Beach, Hawks Nest Beach, Sound View Beach, and Miscellaneous Town Area B. Table 2-5 summarizes the percent of septic systems in each of these four Sub-Areas that were constructed prior to 1980. Septic systems built prior to 1980 typically were not designed to meet long term acceptance rates (LTAR). Therefore, on-site wastewater disposal systems built before 1980 have a very high likelihood of failure due to insufficient soil porosity or loss of acceptance over time, and due to the lack of design and construction controls placed on these systems prior to this date. The significance of this date is that prior to 1980 there were rules pertaining to the design and construction monitoring of onsite wastewater disposal systems, but these requirements were significantly less stringent and enforcement by the State Department of Public Health was ineffective.

Table 2-5 shows that the fraction of septic systems constructed before 1980 in White Sand Beach is approximately one quarter less than that of Sound View Beach and Miscellaneous Town Area B, and half than that of Hawks Nest Beach. Of these four Sub-Areas, White Sand Beach has the smallest fraction of septic systems which may not meet

Figure 0-3:
Regional Wastewater Map



Buy-in costs to share and upgrade (where needed) the existing wastewater infrastructure are issues that are currently being resolved. During design of the recommended combined alternative, these issues will be negotiated with terms detailed in future agreements between the applicable stakeholding parties.

Wastewater flows from each community are envisioned to be measured via magnetic flow meters installed at the discharge of each pump station. The recorded flow measurements would be used as the basis for determining sewer use fees for each community to pay for O&M to downstream communities to convey and treat the wastewater, and intra-association infrastructure O&M.

6) Implementation Plan

The implementation plan for the joint recommended plan has been created and shared activities have already been coordinated between OCBC and OLSBA to eliminate duplication of effort. The schedule is presented below as Table 0-4.

Table 0-4: Overall Schedule including Clean Water Funding Program

(Updated: June 2012)

Activity	Projected Completion Date
Planning Phase (55% Grant) - Wastewater Facilities Planning Report	
• Submit CWF Amendment 3 for Reimbursement	February 2012
• Amend Facilities Plans and Issue Shared Plan	June 2012
• Adopt Recommended Plan	July 2012 (OC)/August 2012 (OLSBA)
• Schedule Meetings with East Lyme, Waterford, New London	February 2012 – June 2012
• Obtain Bond for 100% of Project Cost	August 2012
o Bond allows short term borrowing	
o Short term loan interest starts incurring	
• Negotiate Intermunicipal Agreements (up to 3)	March 2012 - December 2012
• Prepare Application for DEEP Grants/Loans	August 2012 – September 2012
• Submit CWF Application to DEEP	September 2012
Design Phase (25% Grant Funding)	
• Preliminary & Detailed Design - 7 to 12 Months	September 2012 – August 2013
o Aerial Photogrammetry	
o Survey	
o Subsurface Exploration	
o Design	
o Lateral Location Forms	
o Permitting	
• Submit 90% Design for DEEP Review - 1 Month	September 2013
• Finalize Design with DEEP Review Comments - 1 Month	October 2013
• Bid Project for Construction - 4 Months	February 2014
Construction Phase (25% Grant Funding)	
• DEEP Approves Funding Application	March 2014
o DEEP releases reimbursement money for the Design Phase	
o Close out bond	
o DEEP reimburses construction costs monthly	
• Project Construction begins	March 2014
• Project construction ends - 18 months	September 2015
State Clean Water Funding Loan Closing	
• Close loan at the completion of project - within 12 months	September 2016
Levy Benefit Assessments to Repay CWF Loans	October 2015 – October 2016

A conservative estimated annual O&M cost for a centralized sewer system with discharge directly to East Lyme has been updated in Table 0-11 below.

Table 0-11:
Estimated Annual O&M Cost for Centralized Sewer System to East Lyme

O&M COSTS (2012)	Gravity Sewers
Contract Operation Fee	$10,000
Annual Payment to East Lyme for flow treatment at New London WPCF(1)	$25,000
Annual Payment to Point O' Woods for shared pump station cost(2)	$0
Grinder pump equipment short lived asset account(4)	$0
Gas and oil for generator(s)	$200
General Engineering/Legal	$2,000
Audit	$500
Discretionary Fund	$500
Odor Control	$20,000
Short lived asset account (Reserve for capital non-reoccurring)	$10,000
State fees	$300
Billing & Collection	$5,000
Annual O&M Cost (Rounded)	**$74,000**

1) Based on an assumed $5/1000 gallons of wastewater
2) Based on an assumed $5/1000 gallons of wastewater
3) Based on i=4%, t=20 years, PV=-$100,000
4) Based on $40 per Grinder Pump per year

The costs to extend a shared force main to Point O' Woods (POW) and then upgrade the POW pump station for the increased flow rate were evaluated from a shared project perspective. The life cycle cost of connecting to the POW system appears to be more expensive than a connection directly to the East Lyme sewer system. This is based on projected additional sewer user fees POW would charge OCBC and OLSBA, POW pump station upgrade costs, one time infrastructure buy-in fee, and ongoing sharing of O&M costs. The life cycle cost comparison in Table 0-12 summarizes the estimated 20-year savings of discharging directly to East Lyme.

Table 0-12: Life Cycle Cost of Alternatives

Estimated 20-Year Annual Life Cycle Cost Summary for a Centralized Sewer System with Gravity Sewers (costs per EDU)

Discharge Location	OLSBA (-30% to +50%)	OCBC (-30% to +50%)
Point O' Woods	$1,400 to $2,300	$1,100 to $1,800
East Lyme	$1,200 to $2,200	$1,000 to $1,700

Includes one time capital cost annualized over 20 years at 2% interest plus 20 years of annual O+M at 3% inflation.

Estimated 20-Year Total Life Cycle Cost Summary for a Centralized Sewer System with Gravity Sewers (costs per EDU)

Discharge Location	OLSBA (-30% to +50%)	OCBC (-30% to +50%)
Point O' Woods	$35,300 to $57,200	$28,700 to $45,200
East Lyme	$30,700 to $53,900	$24,600 to $42,300

Includes one time capital cost with 20 year/2% loan interest plus 20 years of annual O+M at 3% inflation.

Estimated 20-Year Total Life Cycle Cost Summary

Discharge Location	OLSBA (-30% to +50%)	OCBC (-30% to +50%)
Point O' Woods	$6,784,000 to $10,974,000	$6,237,000 to $9,804,000
East Lyme	$5,889,000 to $10,346,000	$5,343,000 to $9,176,000

Includes one time capital cost with 20 year/2% loan interest plus 20 years of annual O+M at 3% inflation.

Table 0-14

ORDER OF MAGNITUDE OPINION OF COST		FUSS & O'NEILL *Disciplines to Deliver*	SHEET: 1 OF 1
PROJECT:	WASTEWATER FACILITIES PLANNING		DATE 05/03/12
LOCATION:	OLD LYME SHORES BEACH ASSOCIATION		ESTIMATOR: MMJ
DESCRIPTION:	**Gravity Sewer Collection System in OLSBA Study Area**		CHECKED BY: KAM
			PROJECT NO.: 2010.1210.A10

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM DESCRIPTION	UNITS	NUM. OF UNITS	COST PER UNIT	TOTAL COST
8-inch Gravity Sewer	FT	10,800	$85	$918,000
6-inch Force Main, Cleanouts and Valve Chambers	FT	2,220	$75	$166,500
6-inch Service Connection	FT	3,840	$50	$192,000
Sanitary Sewer Manhole	EA	36	$4,000	$144,000
OLSBA Municipal Pump Station	EA	1	$500,000	$500,000
Pump Station Land Easement	EA	1	$25,000	$25,000
Rock Excavation Note 1	CY	1,700	$90	$153,000
Construction Mobilization	LS	1	$50,000	$50,000
Temporary Bituminous Pavement Repair (Association Road)	LF	12,400	$13	$161,200
Mill and Overlay (Association Road) Note 2	SY	14,400	$17	$244,800
Temporary Bituminous Pavement Repair (State Road) Note 3	LF	35	$15	$525
Permanent Bituminous Pavement Repair (State Road) Note 3	LF	35	$20	$700
Mill & Overlay (State Road) Note 3	SY	100	$50	$5,000
TOTAL CONSTRUCTION COST				$2,570,000
SUBTOTAL				$2,570,000
TOTAL COST (-15% TO +30% ROUNDED)				**$2,190,000 TO $3,350,000**

Notes:
1) Assume 1 feet of rock excavation for gravity pipe trenches and no rock excavation for pump station or force main
2) Based on 24' wide road
3) Assume State Road full travel lane Pavement Mill + Overlay with Traffic Control Included
3) Assumes one crossing of Route 156 and pipes to connect northerly streets will be installed in the state road shoulder. Assume State Road crossing is Pavement Mill + Overlay. Includes traffic protection.
4) Assume pump station easement negotiation to include waived assessment for property - value $25,000

FUSS & O'NEILL

Table 0-15

ORDER OF MAGNITUDE OPINION OF COST		FUSS & O'NEILL *Disciplines to Deliver*	SHEET:	1 OF 1
PROJECT:	WASTEWATER FACILITIES PLANNING		DATE	05/03/12
LOCATION:	Old Colony Beach Club		ESTIMATOR:	MMJ
DESCRIPTION:	**Gravity Sewer Collection System in OCBC Study Area**		CHECKED BY:	KAM
			PROJECT NO.:	2010.1210.A10

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s)' methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and does not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs, the Owner shall employ an independent cost estimator.

ITEM DESCRIPTION	UNITS	NUM. OF UNITS	COST PER UNIT	TOTAL COST
8-inch Gravity Sewer	FT	7,600	$85	$646,000
6-inch Force Main, Cleanouts and Valve Chambers	FT	1,800	$75	$135,000
6-inch Service Connection	FT	4,500	$50	$225,000
Sanitary Sewer Manhole	EA	25	$4,000	$101,333
OCBA Municipal Pump Station	EA	1	$500,000	$500,000
Pump Station Land Easement	EA	1	$25,000	$25,000
Rock Excavation Note 1	CY	0	$90	$0
Construction Mobilization	LS	1	$50,000	$50,000
Temporary Bituminous Pavement Repair (Association Road)	LF	9,200	$13	$119,600
Mill and Overlay (Association Road) Note 2	SY	10,200	$17	$173,400
Temporary Bituminous Pavement Repair (State Road) Note 3	LF	0	$15	$0
Permanent Bituminous Pavement Repair (State Road) Note 3	LF	0	$20	$0
Mill & Overlay (State Road) Note 3	SY	0	$50	$0
TOTAL CONSTRUCTION COST				$1,980,000
SUBTOTAL				$1,980,000
TOTAL COST (-15% TO +30% ROUNDED)				**$1,690,000 TO $2,580,000**

Notes:
1) Assume 1 feet of rock excavation for gravity pipe trenches and no rock excavation for pump station or force main
2) Based on 24' wide road
3) Assume State Road full travel lane Pavement Mill + Overlay with Traffic Control Included
3) Assumes one crossing of Route 156 and pipes to connect northerly streets will be installed in the state road shoulder. Assume State Road crossing is Pavement Mill + Overlay. Includes traffic protection.
4) Assume pump station easement negotiation to include waived assessment for property - value $25,000

Table 0-16

ORDER OF MAGNITUDE OPINION OF COST	FUSS & O'NEILL *Disciplines to Deliver*	SHEET: 1 OF 1
PROJECT: WASTEWATER FACILITIES PLANNING		DATE 06/12/11
LOCATION: OLD LYME SHORES BEACH ASSOCIATION		ESTIMATOR: MMJ
DESCRIPTION: **Force Main Crossing Rail Corridor from OLSBA to East Lyme**		CHECKED BY:
		PROJECT NO.: 2010.1210.A10

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and do not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs the Owner shall employ an independent cost estimator.

ITEM DESCRIPTION	UNITS	NUM. OF UNITS	COST PER UNIT	TOTAL COST
6-inch Force Main, Cleanouts and Valve Chambers	FT	13,000	$85	$1,105,000
OLSBA Pump Station Pump Size Increase	EA	1	$60,000	$60,000
Rock Excavation Note 1	CY	722	$90	$65,000
Temporary Bituminous Pavement Repair (State Road) Note 2	LF	13,000	$15	$195,000
Permanent Bituminous Pavement Repair (State Road) Note 2	LF	13,000	$20	$260,000
Mill & Overlay (State Road) Note 2	SY	17,400	$50	$870,000
Stream Crossing	EA	4	$30,000.00	$120,000
East Lyme Sewer Connection Fee Note 3	ALL	0	$1,000,000	$0
Railroad Bridge Crossing Premium Note 4	ALL	1	$200,000	$200,000
TOTAL CONSTRUCTION COST				$2,880,000
SUBTOTAL				$2,880,000
TOTAL COST (-15% TO +30% ROUNDED)				**$2,450,000 TO $3,750,000**

Notes:
1) Rock Excavation Assumed
2) Assume State Road full travel lane Pavement Mill + Overlay. Includes traffic control.
3) Assumes no East Lyme Sewer Connection Fee
4) Assume significant Railroad and DOT work restrictions

Table 0-17

ORDER OF MAGNITUDE OPINION OF COST	FUSS & O'NEILL *Disciplines to Deliver*	SHEET: 1 OF 1
PROJECT: WASTEWATER FACILITIES PLANNING		DATE 05/03/12
LOCATION: OLD LYME SHORES BEACH ASSOCIATION		ESTIMATOR: MMJ
DESCRIPTION: **Force Main Crossing Rail Corridor from OLSBA to Point O' Woods**		CHECKED BY:
		PROJECT NO.: 2010.1210.A10

Since Fuss & O'Neill has no control over the cost of labor, materials, equipment or services furnished by others, or over the Contractor(s methods of determining prices, or over competitive bidding or market conditions, Fuss & O'Neill's opinion of probable Total Project Costs and Construction Cost are made on the basis of Fuss & O'Neill's experience and qualifications and represent Fuss & O'Neill's best judgment as an experienced and qualified professional engineer, familiar with the construction industry; but Fuss & O'Neill cannot and do not guarantee that proposals, bids or actual Total Project or Construction Costs will not vary from opinions of probable cost prepared by Fuss & O'Neill. If prior to the bidding or negotiating Phase the Owner wishes greater assurance as to Total Project or Construction Costs the Owner shall employ an independent cost estimator.

ITEM DESCRIPTION	UNITS	NUM. OF UNITS	COST PER UNIT	TOTAL COST
6-inch Force Main, Cleanouts and Valve Chambers	FT	6,084	$75	$456,300
Rock Excavation Note 1	CY	550	$90	$49,500
Temporary Bituminous Pavement Repair (State Road) Note 2	LF	5,484	$15	$82,260
Permanent Bituminous Pavement Repair (State Road) Note 2	LF	5,484	$20	$109,680
Mill & Overlay (State Road) Note 2	SY	7,400	$50	$370,000
Stream Crossing	EA	2	$30,000	$60,000
East Lyme Sewer Connection Fee Note 3	ALL	0	$1,000,000	$0
Railroad Bridge Crossing Premium Note 4	ALL	1	$200,000	$200,000
POW Pump Station Upgrade	LS	1	$200,000	$200,000
Point O' Woods Connection Fee Note 6	ALL	1	$909,091	$909,091
TOTAL CONSTRUCTION COST				$2,440,000
SUBTOTAL				$2,440,000
TOTAL COST (-15% TO +30% ROUNDED)				**$2,080,000 TO $3,180,000**

Notes:
1) Rock Excavation Assumed
2) Assume State Road full travel lane Pavement Mill + Overlay. Includes traffic protection.
3) Assumes no East Lyme Sewer Connection Fee
4) Assume significant Railroad and DOT work restrictions
5) Cost does not include collection system piping
6) Connection Fee has not yet been negotiated with Point O' Woods and may vary.

Table 0-18

ORDER OF MAGNITUDE OPINION OF COST	FUSS & O'NEILL *Disciplines to Deliver*	SHEET: 1 OF 1
PROJECT: WASTEWATER FACILITIES PLANNING		DATE 06/12/11
LOCATION: OLD LYME SHORES BEACH ASSOCIATION		ESTIMATOR: MMJ
DESCRIPTION: **Off Road Sewer Construction with Directional Drill under Tidal Wetlands to Point O' Woods**		CHECKED BY:
		PROJECT NO.: 2010.1210.A10

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ITEM DESCRIPTION	UNITS	NUM. OF UNITS	COST PER UNIT	TOTAL COST
6-inch Force Main, Cleanouts and Valve Chambers	FT	4,550	$75	$341,250
Directional Drilling Note 1	LF	1,250	$400	$500,000
Rock Excavation Note 2	CY	15,000	$90	$1,350,000
Private Property Sewer Easements	SY	10,000	$10	$100,000
Temporary Bituminous Pavement Repair (Town & POW Road)	LF	700	$13	$9,100
Mill and Overlay (Town & POW Road) Note 3	SY	2,000	$17	$34,000
Temporary Bituminous Pavement Repair (State Road) Note 4	LF	1,600	$15	$24,000
Permanent Bituminous Pavement Repair (State Road) Note 4	LF	1,600	$20	$32,000
Mill & Overlay (State Road) Note 4	SY	2,200	$50	$110,000
Stream Crossing	EA	1	$30,000	$30,000
East Lyme Sewer Connection Fee Note 5	ALL	0	$1,000,000	$0
POW Pump Station Upgrade	LS	1	$200,000	$200,000
Point O' Woods Connection Fee Note 7	ALL	1	$909,091	$909,091
TOTAL CONSTRUCTION COST				$3,640,000
SUBTOTAL				$3,640,000
TOTAL COST (-15% TO +30% ROUNDED)				**$3,100,000 TO $4,740,000**

Notes:
1) Based on past work experience. Actual soil conditions may change price.
2) Rock Excavation Assumed
3) Based on 12 ft wide road
4) Assume State Road is Pavement Mill + Overlay. Includes traffic protection.
5) Assumes no East Lyme Sewer Connection Fee
6) Cost does not include collection piping
7) Connection Fee has not yet been negotiated with Point O' Woods and may vary.

FIGURE 8.2.1 - IMPLEMENTATION SCHEDULE THROUGH PROJECT DESIGN

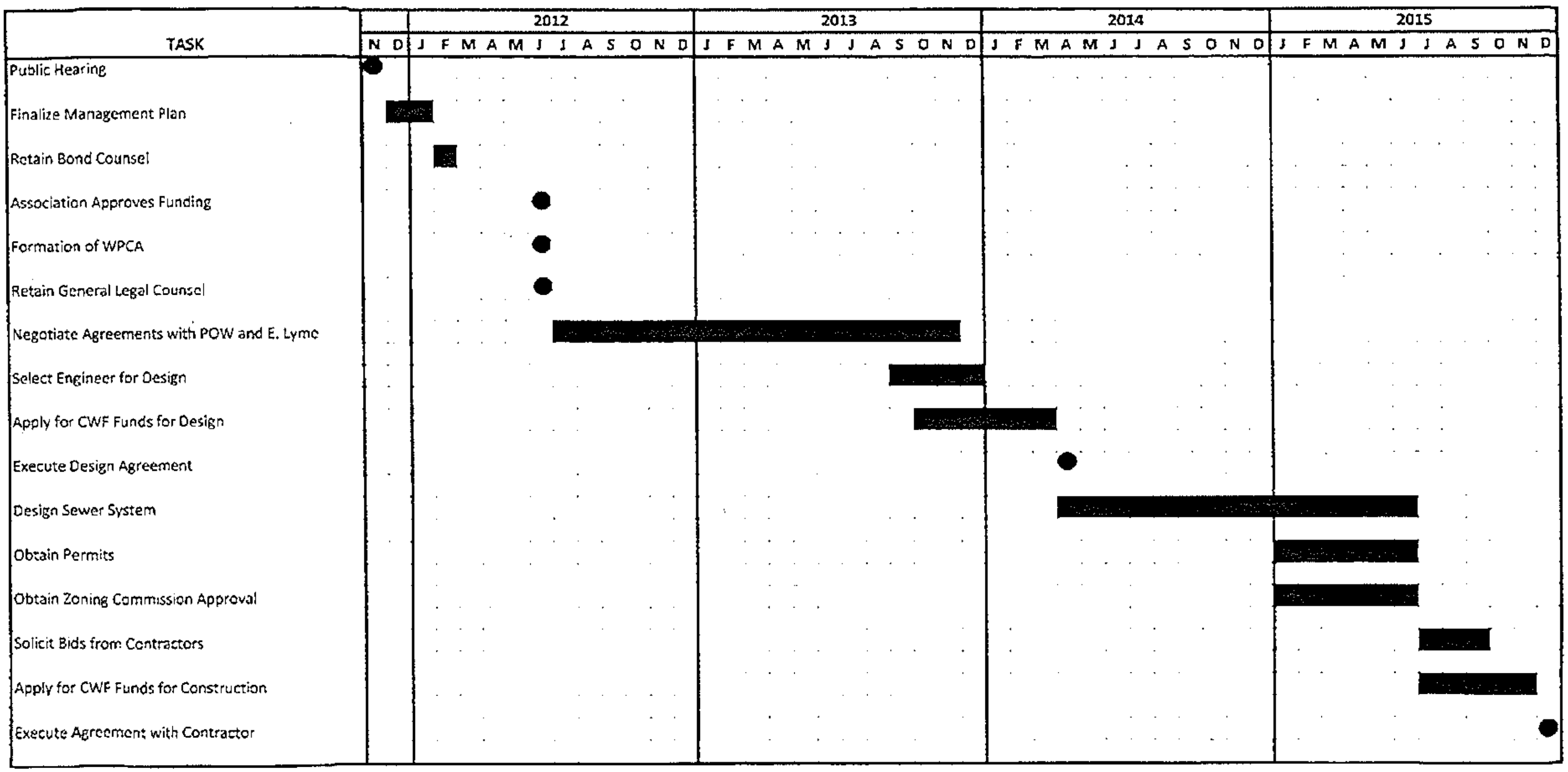

TABLE 7.2.1.1

PRELIMINARY OPINION OF CAPITAL COSTS [1]

SANITARY SEWERS WITH DISCHARGE TO POINT O'WOODS
The Old Colony Beach Club Association
Old Lyme, CT
October 19, 2011

	November 2011 Costs	January 2016 Costs
Construction Cost - Sewer [2]	$3,856,113	$4,257,461
15% Contingency [3]	$578,417	$638,619
Technical Services - Design & Construction [4]	$771,223	$851,492
Legal & Administrative [5]	$192,806	$212,873
Short Term Interest [6]	$330,435	$364,827
Technical Services During Negotiations	$25,000	$27,602
Legal and Administrative Services During Negotiations (5%)	$50,000	$55,204
TOTAL DESIGN & CONSTRUCTION COST:	**$5,803,994**	**$6,408,078**
DEP Grant	**($1,301,438)**	**($1,370,902)**
ESTIMATED NET LOCAL SHARE - SEWER:	**$4,502,555**	**$5,037,176**
Number of EDU's Served	217	217
NET COST PER EDU - SEWER:	**$20,749**	**$23,213**
ANNUAL COST PER EDU - SEWER [7]:	**$1,290**	**$1,442**

NOTES:

(1) All costs developed in 2011 dollars and indexed to year of construction dollars at an annual rate of 2%.

(2) Does not include cost of gravity service connections from building to sewer in street (this cost to be paid by homeowner).
Average connection cost estimated to be $2,500- $5,00 per recent experience in POW.

(3) 15% Contingency used for 2011 estimate. Contingency to be reduced to 10% following design, and 5% following bid opening

(4) Technical Services During Design and Construction estimated @ 20% of construction for planning purposes.
Services include engineering design, topographic survey, test borings, bid & award services, contract administration and resident inspection services

(5) Legal and Administrative Costs estimated @ 5% of construction cost Services include Bond Counsel costs and miscellaneous legal and administrative costs during design and construction of the project.

(6) Short term interest calculated at 2% per year by assuming borrowing half of the total amount over the entire project duration (6 years)

(7) Annual cost per EDU is over a 20-year period at an annual interest rate of 2%.

Old Colony Beach's user fee should be comprised of four elements:

- The fees charged by East Lyme to discharge to its wastewater collection system;
- The fees charged by Point O'Woods to utilize a portion of its wastewater collection system;
- The day-to-day costs incurred by Old Colony Beach to operate and maintain its wastewater collection system; and
- A sinking fund to establish a reserve to pay for the cost to replace equipment.

As a point of reference, Point O'Woods presently charges it's users a flat fee of $200/year for O&M of its wastewater collection system. This fee includes charges it receives from the Town of East Lyme to discharge to its collection system as well as costs to operate, maintain, and administer its own collection system. It should be noted, however, that Point O'Woods system has only been in operation since June of 2010 and they do not yet have a solid handle on their operating costs; consequently, the figure cited above is likely to change (either up or down) as time goes by and more cost data becomes known. Regardless, because Old Colony Beach would be a user of Point O' Woods' system, which in turn is a user of East Lyme's system, Old Colony Beach should anticipate that its fee should be equal to the fee charged by Point O'Woods plus the cost to operate and maintain Old Colony Beach's system. Terms and conditions for the payment of O&M fees to both Point O'Woods and East Lyme would be spelled out in the respective intermunicipal agreements with Old Colony Beach. The estimated costs for O&M of the Old Colony Beach sewer system are given in Table 7.2.2.1. Under the recommended alternative, the cost per equivalent dwelling unit (EDU) is estimated to be $311 annually for O&M costs.

power for the proposed pump station, costs for fuel and chemicals that are expended, and contracted services for system O&M,. The annual O&M cost associated solely with the Old Colony Beach sewer system is estimated to be $110 per building. Note that these charges are estimated in 2011 dollars and may differ somewhat from future costs.

It is projected that each single-family house will pay a total of $310 annually for O&M costs.

7.5 Average Connection Cost

Properties would be required to pay the cost of connecting their house to the lateral sewer in the street. The projected average cost of a building connection has been estimated at $2,500 to $5,000 per connection per recent experience in Point O'Woods. The actual cost would vary and depend on such factors as the presence of bedrock, high groundwater, extensive landscaping, etc.

7.6 Summary of Local Costs

The average annual sewer assessment (capital costs) is estimated to be $1,442 per building served. The average annual user fee (O&M costs) is estimated to be $310 per building served. Adding these costs results in a total estimated average annual cost for a single-family dwelling unit of $1,752.

7.7 Financial Capability

Old Colony Beach should consult its charter to determine if there are any limits on the amount that it may borrow. To qualify for Clean Water Funds, Old Colony Beach

TABLE 7.2.2.1

ESTIMATE OF O&M COSTS FOR SEWER USERS CONNECTING TO THE POINT O' WOODS SEWER SYSTEM[1]

(Recommended Alternative)

Old Colony Beach Club Association
Old Lyme, Connecticut

October 2011

Item	Annual Cost
1. Existing Point O'Woods Sewer User Fee	$200
2. New Sewer User Fee [2] (Old Colony Beach O&M Only Costs)	$111
Total Annual Cost per EDU [3]:	**$311**

Notes:

1. All costs in 2011 dollars.
2. Includes costs for O&M Contractor, Power, Techical, Admin. and sinking fund as indicated below exclusive to Old Colony Beach Club Association.
3. Based on 217 EDU's. This figure reflects the estimated number of initial units to be served by the proposed sewer system.

Item		
O&M Contractor		$10,000
Power & Chemicals		$5,000
Technical		$2,500
Sinking Fund		$2,500
Admin		$2,000
Misc.		$2,000
	Total	$24,000
	Cost Per Building Served	$111

RFP Engineering, LLC

CONSTRUCTION COST ESTIMATE

Date 16-Oct-11

Project: Old Colony Beach Waswtewater Management Plan

Description COLLECTION SYSTEM WITHIN OLD COLONY BEACH

ALL COSTS ARE IN 2011 DOLLARS

ITEM	UNIT	EST. QTY	UNIT PRICE	TOTAL
Gravity Sewer - Local Roads				
6" PVC	LF	6,000	$50	$300,000
8" PVC	LF	6,237	$75	$467,775
10" PVC	LF	700	$85	$59,500
12" PVC	LF		$100	$0
Force Main - Local Roads				
3" DIP	LF		$50	$0
4" DIP	LF		$65	$0
6" DIP	LF		$80	$0
Force Main - State Roads				
3" DIP	LF		$60	$0
4" DIP	LF		$75	$0
6" DIP	LF		$100	$0
Tee/Wye	EA	225	$300	$67,500
Manholes				
Gravity	EA	33	$3,000	$99,000
Force Main	EA		$4,500	$0
Pumping Stations	EA	1	$400,000	$400,000
Site Acquisition	LS			$0
RR Crossings				
Jacking	LS		$150,000	$0
Trenching	LS		$25,000	$0
Stream/River Crossing				
	LS		$30,000	$0

ITEM	UNIT	EST. QTY	UNIT PRICE	TOTAL
Bituminous Pavement				
State Temp	SY		$20	$0
State Perm	SY		$12	$0
Local Temp	SY	4,518	$9	$40,662
Local Perm	SY	19,567	$12	$234,804
Rock Removal				
Mechanical	CY		$250	$0
Blasting	CY		$125	$0
Maintenance and Protection of Traffic				
	ALLOW	1		$0
			Subtotal:	$1,669,241
			Contingency (@15%):	$250,386
			Total Estimated Cost:	**$1,919,627**

CONSTRUCTION COST ESTIMATE

Date: October 16, 2011

Project: Old Colony Beach Waswtewater Management Plan

Description: CONNECTION TO EAST LYME SEWER SYSTEM

ALL COSTS ARE IN 2011 DOLLARS

ITEM	UNIT	EST. QTY	UNIT PRICE	TOTAL
Gravity Sewer - Local Roads				
6" PVC	LF	6,000	$50	$300,000
8" PVC	LF	6,237	$75	$467,775
10" PVC	LF	700	$85	$59,500
12" PVC	LF		$100	$0
Force Main - Local Roads				
3" DIP	LF		$50	$0
4" DIP	LF	1,000	$65	$65,000
6" DIP	LF		$80	$0
Force Main - State Roads				
3" DIP	LF		$60	$0
4" DIP	LF	12,400	$75	$930,000
6" DIP	LF		$100	$0
Tee/Wye	EA	225	$300	$67,500
Manholes				
Gravity	EA	33	$3,000	$99,000
Force Main	EA	5	$4,500	$22,500
Pumping Stations	EA	2	$400,000	$800,000
Site Acquisition	LS	1	$100,000	$100,000
RR Crossings				
Jacking	LS	1	$150,000	$150,000
Trenching	LS		$25,000	$0
Stream/River Crossing				
	LS	2	$30,000	$60,000

ITEM	UNIT	EST. QTY	UNIT PRICE	TOTAL
Bituminous Pavement				
State Temp	SY	11,022	$20	$220,444
State Perm	SY	34,444	$12	$413,333
Local Temp	SY	4,518	$9	$40,662
Local Perm	SY	19,567	$12	$234,804
Rock Removal				
Mechanical	CY	100	$250	$25,000
Blasting	CY	500	$125	$62,500
Maintenance and Protection of Traffic				
	ALLOW	1	$80,000	$80,000

Subtotal	$4,198,019
Contingency (15%):	$629,703
Technical Services During Intermunicipal Negotiations:	$75,000
Technical Services @ 20%:	$839,604
Legal and Administrative @ 3%.	$125,941
Short Term Interest:	$359,185
Subtotal:	$6,227,451
DEP Grant:	-$1,416,831
Net Local Share:	**$4,810,619**

Background Information Readings Effecting Transport of Sewage in Groundwater Aquifers

M

Point and Nonpoint Sources of Contaminants

Contaminants may be present in water or in air as a result of natural processes or through mechanisms of displacement and dispersal related to human activities. Contaminants from point sources discharge either into ground water or surface water through an area that is small relative to the area or volume of the receiving water body. Examples of point sources include discharge from sewage-treatment plants, leakage from gasoline storage tanks, and seepage from landfills (Figure M–1).

Nonpoint sources of contaminants introduce contaminants to the environment across areas that are large compared to point sources, or nonpoint sources may consist of multiple, closely spaced point sources. A nonpoint source of contamination that can be present anywhere, and affect large areas, is deposition from the atmosphere, both by precipitation (wet deposition) or by dry fallout (dry deposition). Agricultural fields, in aggregate, represent large areas through which fertilizers and pesticides can be released to the environment.

The differentiation between point and nonpoint sources of contamination is arbitrary to some extent and may depend in part on the scale at which a problem is considered. For example, emissions from a single smokestack is a point source, but these emissions may be meaningless in a regional analysis of air pollution. However, a fairly even distribution of tens or hundreds of smokestacks might be considered as a nonpoint source. As another example, houses in suburban areas that do not have a combined sewer system have individual septic tanks. At the local scale, each septic tank may be considered as point source of contamination to shallow ground water. At the regional scale, however, the combined contamination of ground water from all the septic tanks in a suburban area may be considered a nonpoint source of contamination to a surface-water body.

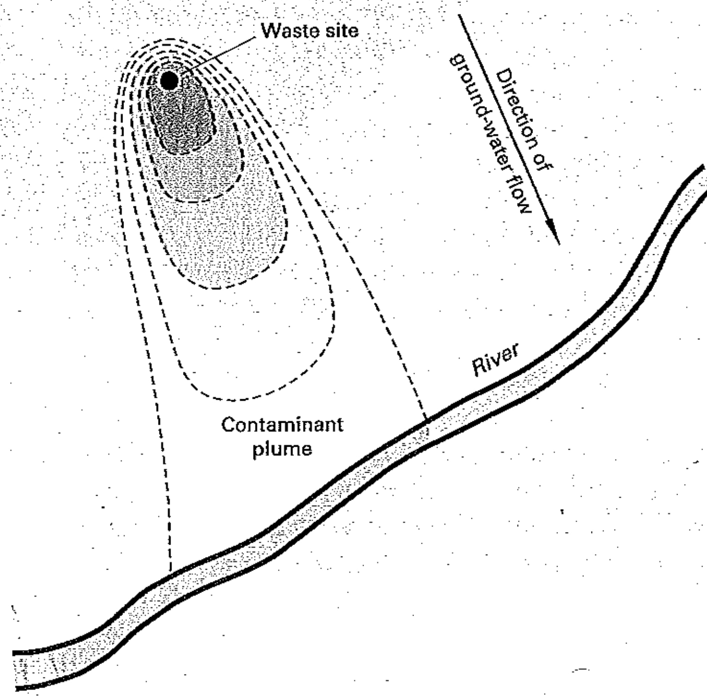

Figure M–1. *The transport of contamination from a point source by ground water can cause contamination of surface water, as well as extensive contamination of ground water.*

D

Some Common Types of Biogeochemical Reactions Affecting Transport of Chemicals in Ground Water and Surface Water

ACID-BASE REACTIONS

Acid-base reactions involve the transfer of hydrogen ions (H^+) among solutes dissolved in water, and they affect the effective concentrations of dissolved chemicals through changes in the H^+ concentration in water. A brief notation for H^+ concentration (activity) is pH, which represents a negative logarithmic scale of the H^+ concentration. Smaller values of pH represent larger concentrations of H^+, and larger values of pH represent smaller concentrations of H^+. Many metals stay dissolved when pH values are small; increased pH causes these metals to precipitate from solution.

PRECIPITATION AND DISSOLUTION OF MINERALS

Precipitation reactions result in minerals being formed (precipitated) from ions that are dissolved in water. An example of this type of reaction is the precipitation of iron, which is common in areas of ground-water seeps and springs. At these locations, the solid material iron hydroxide is formed when iron dissolved in ground water comes in contact with oxygen dissolved in surface water. The reverse, or dissolution reactions, result in ions being released into water by dissolving minerals. An example is the release of calcium ions (Ca^{++}) and bicarbonate ions (HCO_3^-) when calcite ($CaCO_3$) in limestone is dissolved.

SORPTION AND ION EXCHANGE

Sorption is a process in which ions or molecules dissolved in water (solutes) become attached to the surfaces (or near-surface parts) of solid materials, either temporarily or permanently. Thus, solutes in ground water and surface water can be sorbed either to the solid materials that comprise an aquifer or streambed or to particles suspended in ground water or surface water. The attachments of positively charged ions to clays and of pesticides to solid surfaces are examples of sorption. Release of sorbed chemicals to water is termed desorption.

When ions attached to the surface of a solid are replaced by ions that were in water, the process is known as ion exchange. Ion exchange is the process that takes place in water softeners; ions that contribute to water hardness—calcium and magnesium—are exchanged for sodium on the surface of the solid. The result of this process is that the amount of calcium and magnesium in the water declines and the amount of sodium increases. The opposite takes place when saltwater enters an aquifer; some of the sodium in the saltwater is exchanged for calcium sorbed to the solid material of the aquifer.

OXIDATION-REDUCTION REACTIONS

Oxidation-reduction (redox) reactions take place when electrons are exchanged among solutes. In these reactions, oxidation (loss of electrons) of certain elements is accompanied by the reduction (gain of electrons) of other elements.

For example, when iron dissolved in water that does not contain dissolved oxygen mixes with water that does contain dissolved oxygen, the iron and oxygen interact by oxidation and reduction reactions. The result of the reactions is that the dissolved iron loses electrons (the iron is oxidized) and oxygen gains electrons (the oxygen is reduced). In this case, the iron is an electron donor and the oxygen is an electron acceptor. Bacteria can use energy gained from oxidation-reduction reactions as they decompose organic material. To accomplish this, bacterially mediated oxidation-reduction reactions use a sequence of electron acceptors, including oxygen, nitrate, iron, sulfate, and carbon dioxide. The presence of the products of these reactions in ground water and surface water can be used to identify the dominant oxidation-reduction reactions that have taken place in those waters. For example, the bacterial reduction of sulfate (SO_4^{2-}) to sulfide (HS^-) can result when organic matter is oxidized to CO_2.

BIODEGRADATION

Biodegradation is the decomposition of organic chemicals by living organisms using enzymes. Enzymes are specialized organic compounds made by living organisms that speed up reactions with other organic compounds. Microorganisms degrade (transform) organic chemicals as a source of energy and carbon for growth. Microbial processes are important in the fate and transport of many organic compounds. Some compounds, such as petroleum hydrocarbons, can be used directly by microorganisms as food sources and are rapidly degraded in many situations. Other compounds, such as chlorinated solvents, are not as easily assimilated. The rate of biodegradation of an organic chemical is dependent on its chemical structure, the environmental conditions, and the types of microorganisms that are present. Although biodegradation commonly can result in complete degradation of organic chemicals to carbon dioxide, water, and other simple products, it also can lead to intermediate products that are of environmental concern. For example, deethylatrazine, an intermediate degradation product of the pesticide atrazine (see Box P), commonly is detected in water throughout the corn-growing areas of the United States.

DISSOLUTION AND EXSOLUTION OF GASES

Gases are directly involved in many geochemical reactions. One of the more common gases is carbon dioxide (CO_2). For example, stalactites can form in caves when dissolved CO_2 exsolves (degasses) from dripping ground water, causing pH to rise and calcium carbonate to precipitate. In soils, the microbial production of CO_2 increases the concentration of carbonic acid (H_2CO_3), which has a major control on the solubility of aquifer materials. Other gases commonly involved in chemical reactions are oxygen, nitrogen, hydrogen sulfide (H_2S), and methane (CH_4). Gases such as chlorofluorocarbons (CFCs) and radon are useful as tracers to determine the sources and rates of ground-water movement (see Box G).

III. ENVIRONMENTAL POLLUTION

Exercise III-4. Simplified Principles of Groundwater Hydrology

INTRODUCTION

Groundwater is an important component of the hydrologic cycle. It feeds lakes, rivers, wetlands, and reservoirs; it supplies water for domestic, municipal, agricultural, and heating and cooling systems. Groundwater resources at a site vary with natural and artificial recharge and discharge conditions. Because we dispose of wastes improperly or mishandle materials on the land surface, we pollute some groundwater reservoirs. For resource planning and waste management, it is essential that we understand the quantity, quality, and movement of water in the subsurface. This exercise is an introduction to the basics of groundwater hydrology (hydrogeology).

Part of the water that reaches the land in the form of precipitation infiltrates to become groundwater. Groundwater occurs in openings in rocks and unconsolidated materials (Figure III-4.1) and moves under the influence of gravity or pressure. An aquifer or groundwater reservoir is a water-saturated geologic unit that yields water to wells or springs. Generally, unconsolidated materials such as sand and gravel have more spaces than solid rock; the openings are due to incomplete cementation of the grains or to fracturing or partial solution of the rock. Openings in igneous and metamorphic rocks are generally due to fractures and joints. The ratio of the open spaces relative to the rock volume is called *porosity*, which is expressed as a percentage (Table III-4.1). Porosity is a storage factor.

Not all of the water stored in an aquifer can be removed because of molecular forces and surface tension. The volume of water that can be removed by gravity drainage is the *specific yield* (Table III-4.1), while the quantity retained is the *specific retention*. Both terms are expressed as percentages. Specific yield plus specific retention equals porosity.

The ease with which water moves through a rock is a measure of its *permeability*, which can be expressed as gallons per day per square foot (gpd/ft^2). This property of a material is sometimes referred

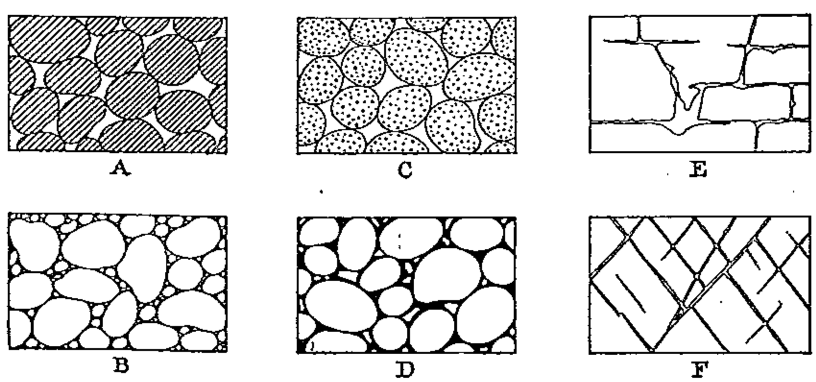

FIGURE III-4.1 Diagram showing several types of rock interstices and the relation of rock texture to porosity: A, well-sorted sedimentary deposit having high porosity; B, poorly sorted sedimentary deposit having low porosity; C, well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; D, well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; E, rock rendered porous by solution; F, rock rendered porous by fracturing. (Meinzer, 1923, p. 3) to as hydraulic conductivity. Some materials, such as clay, may have a high porosity but a low permeability because the openings are either not interconnected or are very small. Aquifers that are highly permeable provide large quantities of water to wells.

In some aquifers groundwater occurs under water-table or unconfined conditions (Figure III-4.2). In this case the water table is the boundary between the zones of aeration and saturation. Where the water-table intersects the land surface, springs, seeps, streams, and lakes are formed. The position of the water table can be determined by measuring the depth to water in a well tapping an unconfined aquifer.

Many aquifers are confined by layers of low permeability, and water in them is stored under pressure (Figure III-4.2). When a well is drilled into such a confined or artesian aquifer, water rises in the well to some level above the base of the confining bed. In some cases the well may even flow at land surface. The water level (also known as the potentiometric, piezometric, or water-pressure surface) represents the artesian pressure in the confined aquifer.

Most commonly the water table forms a gently sloping surface that follows the land surface (i.e., higher under hills than adjacent valleys). The water-pressure surface in artesian systems also generally follows topographic contours but in a more subdued manner. When the water table is at or near the land surface, groundwater may evaporate or be transpired by plants in large quantities and thus returned to the atmosphere.

TABLE III-4.1 Range in Hydrologic Properties of Selected Rocks

NAME	POROSITY %	SPECIFIC YIELD %	PERMEABILITY gpd/ft²
Gravel	30-40	15-30	1000-8000
Sand	35-40	10-30	100-3000
Clay, Silt	45-55	1-10	0.001-2
Till	20-40	6-16	0.002-24
Sandstone	10-20	5-15	0.1-50
Shale	1-10	0.5-5	0.00001-0.1
Limestone	1-10	0.5-5	40*
Igneous rocks	0-40	0-30	0-35*
Metamorphic rocks	0-40	0-30	0-35*

* Highly variable

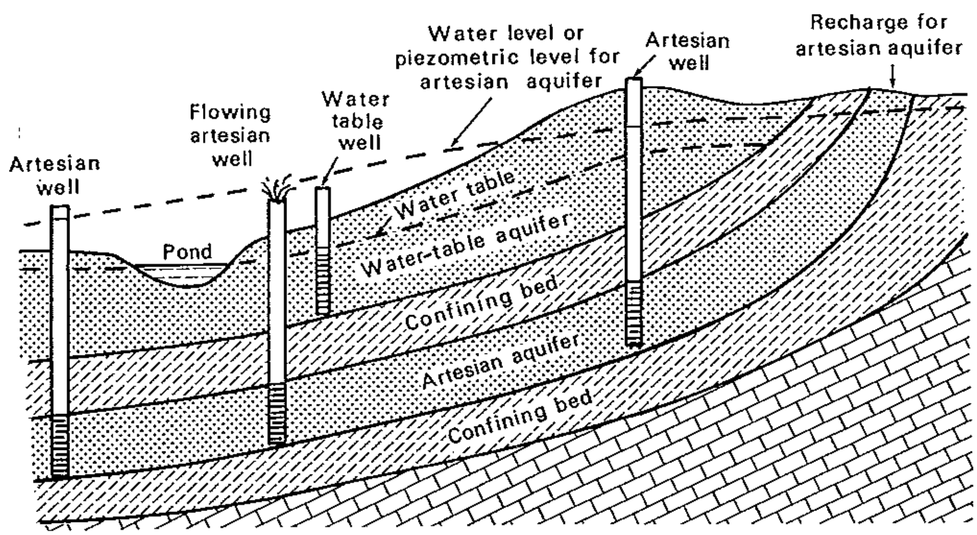

FIGURE III-4.2 Schematic diagram of artesian and water-table aquifers.

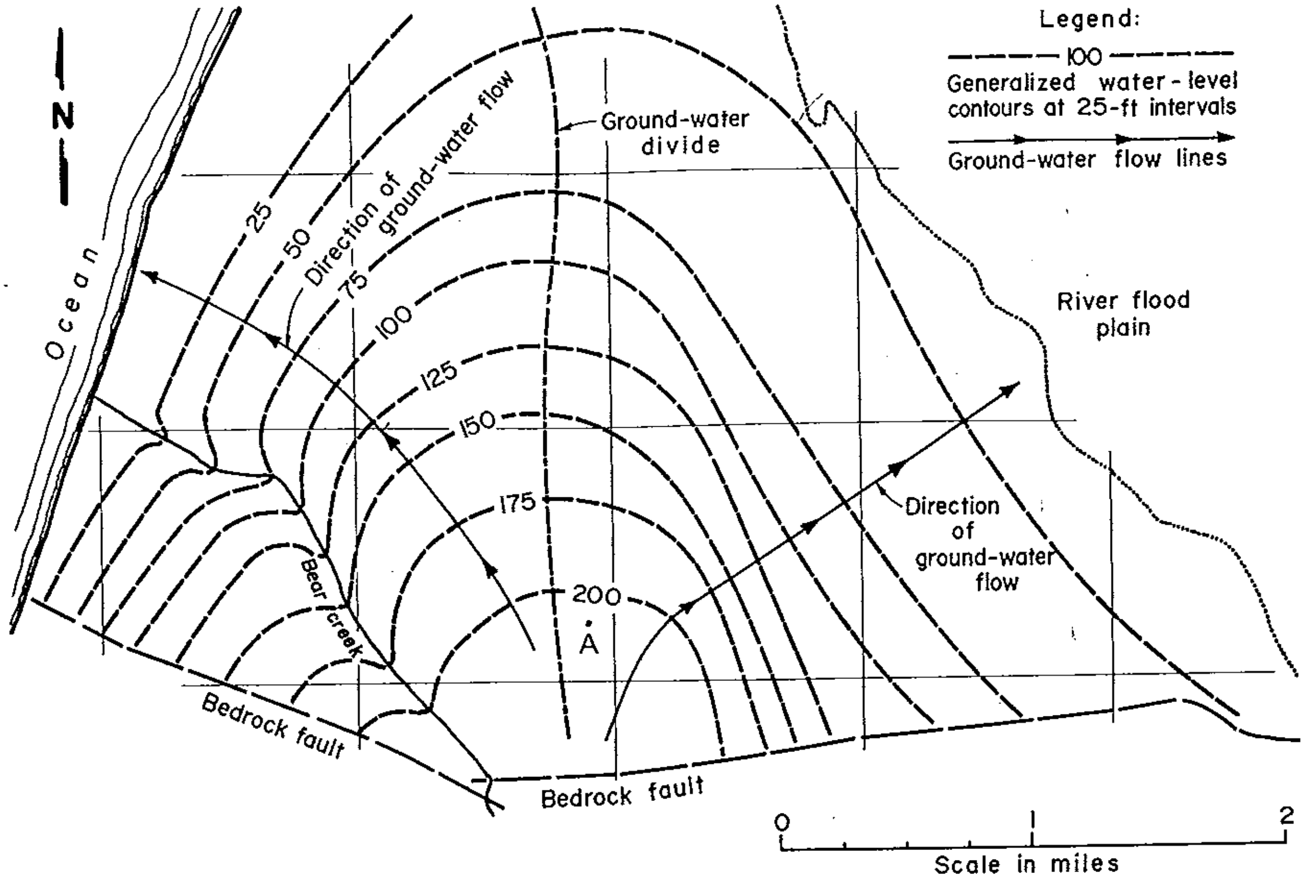

FIGURE III-4.3 Water-level contour map showing elevation of the upper surface of the saturated zone. Groundwater flows down-gradient at right angles to the contours, as shown by the two flow lines that have been added to the map. (Modified from Johnson, 1966, p. 40)

The water table or water-pressure surface can be mapped in a manner similar to contouring surface topography (Figure III-4.3). In this case, however, control points are water elevations in wells, springs, lakes, or streams.

The hydraulic gradient (*I*) is the difference in water level per unit of distance in a given direction. It can be measured directly from water-level maps in feet per foot or feet per mile. The direction of groundwater flow can be indicated by flow lines, which are drawn perpendicular to water-level contours (Figure III-4.3).

By using water-level maps in conjunction with topographic maps, the depth to the water table or water-pressure surface can be determined. This depth will vary with time depending on the season and the amount of recharge supplied by precipitation infiltrating the aquifer and the amount of discharge by pumping and by natural outflow to springs and streams. If discharge exceeds the rate of recharge to the aquifer, the water level in the aquifer will decline, and some wells could become dry.

The rate of groundwater flow generally ranges from 5 ft/day to 5 ft/year. It is usually less than 1 ft/day, but velocities greater than 400 ft/day have been measured. Groundwater velocity [*v*] depends on permeability (or hydraulic conductivity) [*P*], the hydraulic gradient [*I*], and the specific yield [*a*]. There are 7.48 gal per cubic foot. The following relationship is used to determine groundwater velocity in ft/day, where a is given as a decimal percent (i.e., 10 percent = 0.10) and I is in ft/ft.

$$v = \frac{PI}{7.48a}$$

The quantity of groundwater [Q], in gallons per day, that passes through a cross-sectional area of an aquifer can be determined by means of Darcy's Law:

$$Q = PIA$$

where A, the cross-sectional area through which flow occurs, is equal to the width of the aquifer times its saturated thickness. Darcy's Law shows that the quantity of flow increases with an increase in P, I, or A. The following questions are based on the conditions shown in Figure III-4.3.

QUESTIONS (III-4)

1. What is the average water-level gradient or slope along the western flow line?
2. If the aquifer indicated is 20 ft thick and has a porosity of 20 percent, how much water, in cubic feet, is stored in a 1-square-mile area? (Multiply by 7.48 to convert to gallons.)
3. If the permeability of the aquifer is 1000 gpd/ft^2, and its specific yield is 15 percent, what is the groundwater velocity in the vicinity of the western flow line?
4. Construct a flow line on the figure from site A. In what direction is the water moving?
5. If gasoline were spilled at site A, would it discharge directly into the ocean? Explain.
6. Briefly describe the surface topography of the area in the figure.

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Exercise III-5. Groundwater Contamination from Waste Disposal Ponds

INTRODUCTION

Groundwater may be contaminated by accident or by improper storage or disposal of wastes at the surface. Improper storage or disposal has occurred in many areas due to our ignorance about groundwater flow and potential health effects, the lack of concern for water supplies ("we have other sources"), and a short-term view of the behavior of groundwater and our future needs of water.

In this exercise we look at a case where industry used pits to dispose of or store liquid wastes. In the past it was expedient to create waste ponds where the wastes decreased in volume through evaporation or infiltration. In this study, we explore the cause and extent of contamination from oil field brines.

In many oil-producing areas, severe problems of groundwater contamination are common. These are caused primarily by the infiltration of saltwater into the ground. Saltwater, or brine, is produced with the oil and, since the brine often is a by-product of little or no economic value, when otherwise unregulated it is commonly disposed of in the most economical manner possible. In some areas this is done by reinjection into the producing zone by means of a well. In others it is accomplished by pumping the brine into holding ponds or pits, where a small percentage evaporates but most of it infiltrates. Infiltration can lead to severe groundwater pollution since the chloride concentrations of the brines may exceed 35,000 mg/l.[1] Once the oil wells and pits are abandoned, the chemical quality of the groundwater tends to improve, usually very slowly, as the concentrated solutions migrate to areas of discharge such as springs, streams, or wells. The natural flushing of the groundwater system depends on the permeability of the rocks, the hydraulic gradient, the effective porosity, and the amount and rate of infiltration of rain and snowmelt. It may require decades for the groundwater system to return to its natural chemical state. The rate of flushing and the amount of time that the groundwater reservoir remains contaminated are of profound interest in legal cases where an action for damages has been initiated.

The brines sterilize the soil, kill vegetation, and create an undesirable taste in drinking water. The concentration at which a brine becomes harmful to vegetation depends on the type of plant, the depth of the root system, the season, and the depth of the water table, to mention only a few factors. Dead trees and other vegetation, however, commonly mark areas where brine-contaminated groundwater discharges into streams or where it flows from springs. The USEPA recommends that drinking water contain no more than 250 mg/l of chloride, since higher concentrations cause a salty taste. Higher concentrations are not likely to cause illness in humans because the water is too salty for consumption.

Groundwater Contamination Near Delaware, Ohio

This part of the exercise is based on several studies conducted at a brine-contaminated site on the nearly flat floodplain of the Olentangy River in Ohio. Three oil wells were drilled in this area in June 1964. The brine-to-oil ratio was about 10:1, and nearly 236,000 barrels of salt water were pumped into

[1] In contrast many areas have groundwater with chloride concentrations of less than 25 mg/l. Sea water is less salty than the brines, with a chlorinity of 19,000 mg/l, which makes up 55 percent of the total salt content of sea water.

three ponds from June 1964 to July 1965. Dissolved solids in the brine averaged 60,000 mg/l, and of this about 35,000 mg/l consisted of the chloride ion (Pettyjohn, 1971).

The accompanying figures (Figures III-5.1, 5.2, 5.3) show the location of four brine-disposal pits, three oil wells, 25 observation wells, and a water well. The observation wells averaged 25 ft in depth and were installed in late 1965, following cessation of brine disposal, to monitor the movement of the contaminated groundwater. Shale bedrock is less than 30 ft deep and is overlain by alluvial material consisting of a mixture of sand, silt, and clay. The average permeability (*P*) of the alluvial material, which contains the contaminated water, is about 200 gpd/ft^2, and the average effective porosity (*a*) is 0.15. The water table gradient (*I*) can be determined from a water-table map.

The objectives of the exercise are to determine the direction and rate of flow of the contaminants in the ground and to evaluate the possible contamination of a nearby water well.

QUESTIONS (III-5)

1. Using the data in Table III-5.1, construct a water-table map (Figure III-5.1). Begin by transferring the water-table elevations from Table III-5.1 to the appropriate test hole locations in Figure III-5.1. Then contour the water-surface elevations using a contour interval of 2 ft. The contours should roughly parallel the 864-ft contour already drawn.

TABLE III-5.1 Chloride Content of Wells and Water-Table Elevation in the Delaware Area

WELL NO.	WATER-TABLE ELEVATION (March 1969)	CHLORIDE CONTENT (mg/l)		
		Nov. 1965	Oct. 1966	March 1969
1	867	4,500	288	24
2	871	--	875	36
3	866	12	12	12
4	869	--	12,000	200
5	862	--	8,000	400
6	868	18,000	8,875	407
7	868	--	26,250	662
8	865	--	1,000	490
9	870	--	14	16
10	868	25,500	9,850	917
11	868	31,000	7,500	550
12	864	--	8,750	740
13	865	--	6,875	1,355
14	864	--	3,125	292
15	864	--	1,725	302
16	864	22,750	15,500	1,230
17	868	--	10,000	1,300
18	864	5,600	1,500	600
19	869	27	25	300
20	862	--	15,000	1,400
21	865	--	9,000	1,100
22	862	4,800	4,800	117
23	859	5,250	6,625	779
24	861	33	235	27
25	860	95	--	40
W-1	880	--	20	320

2. Draw several flow lines originating at the brine holding ponds to the most likely area of groundwater discharge. Remember that during dry weather streams flow only because groundwater discharges into them.

3. What is the gradient from pond C to the Olentangy River? ______________ ft/ft.

4. What is the gradient from pond C to Saunders Creek? ______________ ft/ft.

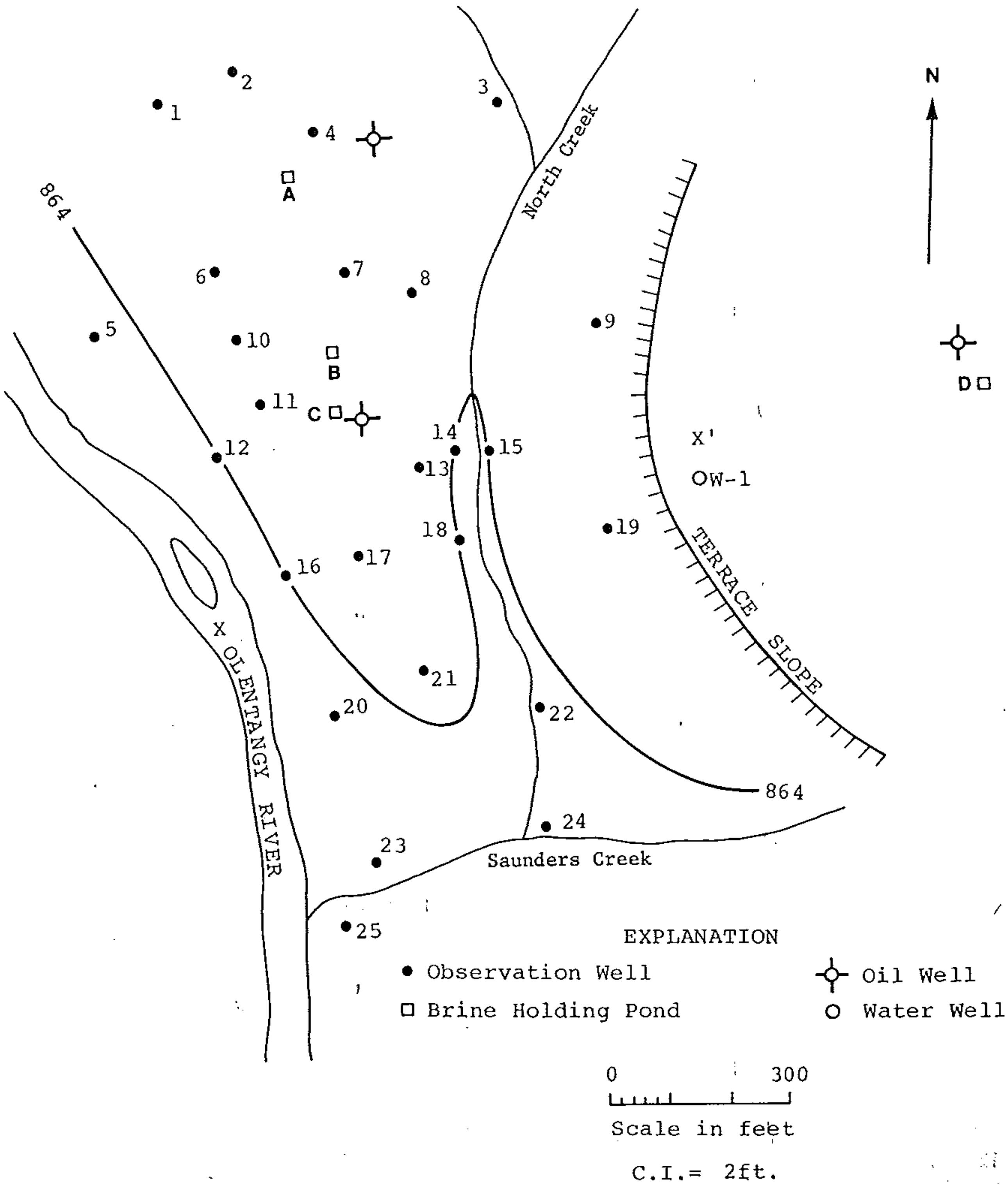


FIGURE III-5.1 Map showing configuration of the water table in March 1969.

5. Calculate the velocity of groundwater moving from pond C to the Olentangy River and from pond C to Saunders Creek using the following formula and the data given earlier in this exercise on the hydraulic characteristics of the unconsolidated material.

$$v = \frac{PI}{7.48\,a}$$

where v = velocity (ft/day)
P = permeability (gal/day/ft^2)
I = gradient (ft/ft)
a = specific yield (% as a decimal)

a. The velocity of groundwater from pond C to the Olentangy River is about ____________ ft/day.

b. The velocity of groundwater from pond C to Saunders Creek is about ____________ ft/day.

6. If we divide the distance of travel (measured along a flow line) by the rate of flow of groundwater, we obtain the travel time. What are the travel times for water from pond C to

a. Olentangy River:

b. Saunders Creek:

7. On another map (Figure III-5.2) construct contours representing lines of equal chloride concentrations (isochlors). Use the data for October 1966 (Table III-5.1) and a contour interval of 5,000 mg/l. Consider the direction of groundwater flow when drawing these contours.

8. Should the Olentangy River and Saunders and North creeks contain higher than normal concentrations of chloride in the vicinity of the contaminated area? _______ Why?

9. Why did wells 23 and 24 contain higher concentrations of chloride in October 1966 than in November 1965, while all the other wells contained less?

10. What do you think the chloride concentration of the groundwater was before brine-pit disposal began?

11. What techniques might be used to increase the rate of flushing of the high-chloride water in the contaminated area?

12. A second isochlor map, based on the March 1969 data, is shown in Figure III-5.3. A contour interval of 300 mg/l was used. This map is useful in determining the change in contamination with time. Compare Figures III-5.2 and 5.3 and describe the changes that have occurred.

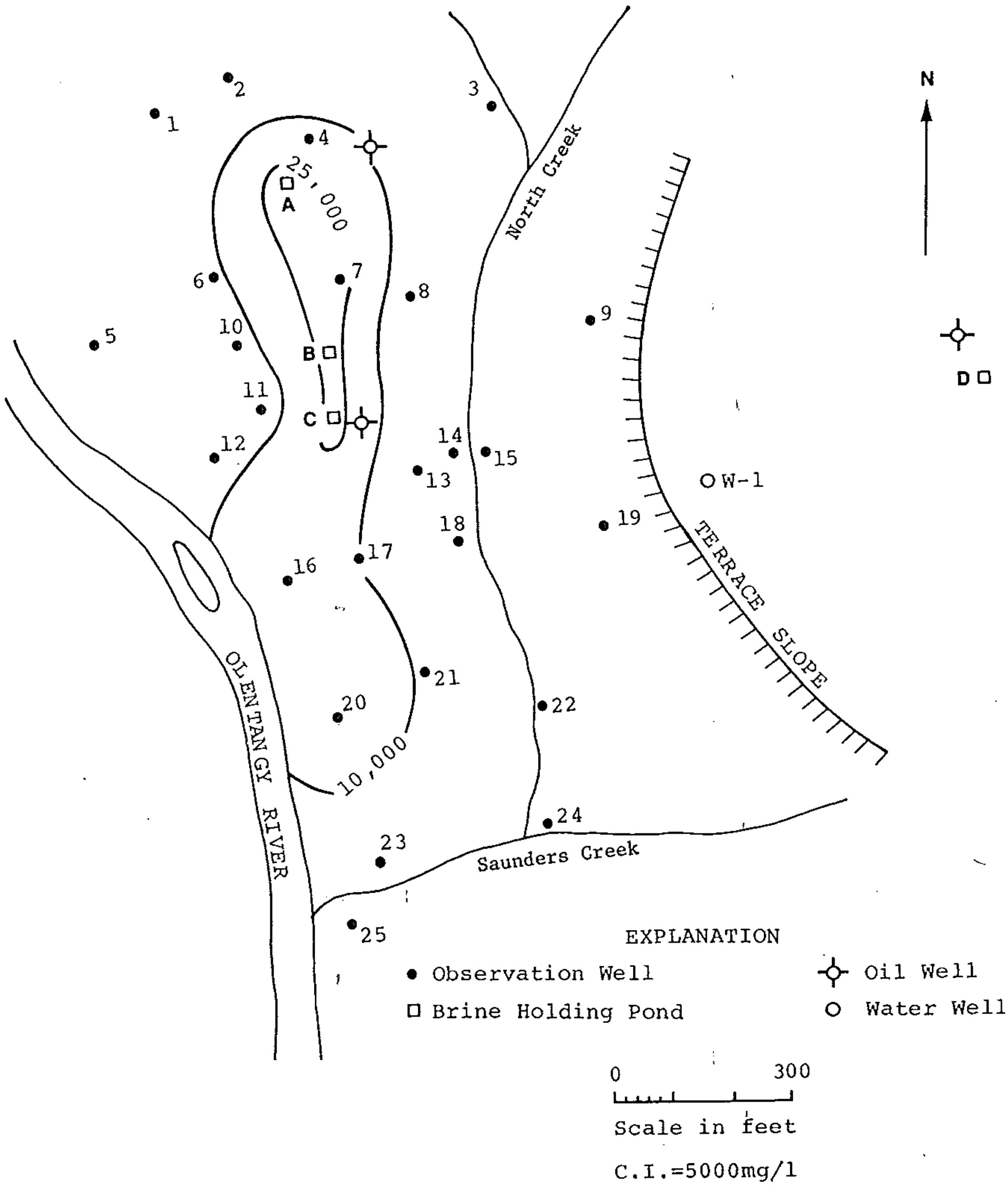


FIGURE III-5.2 Map showing groundwater isochlors in October 1966.

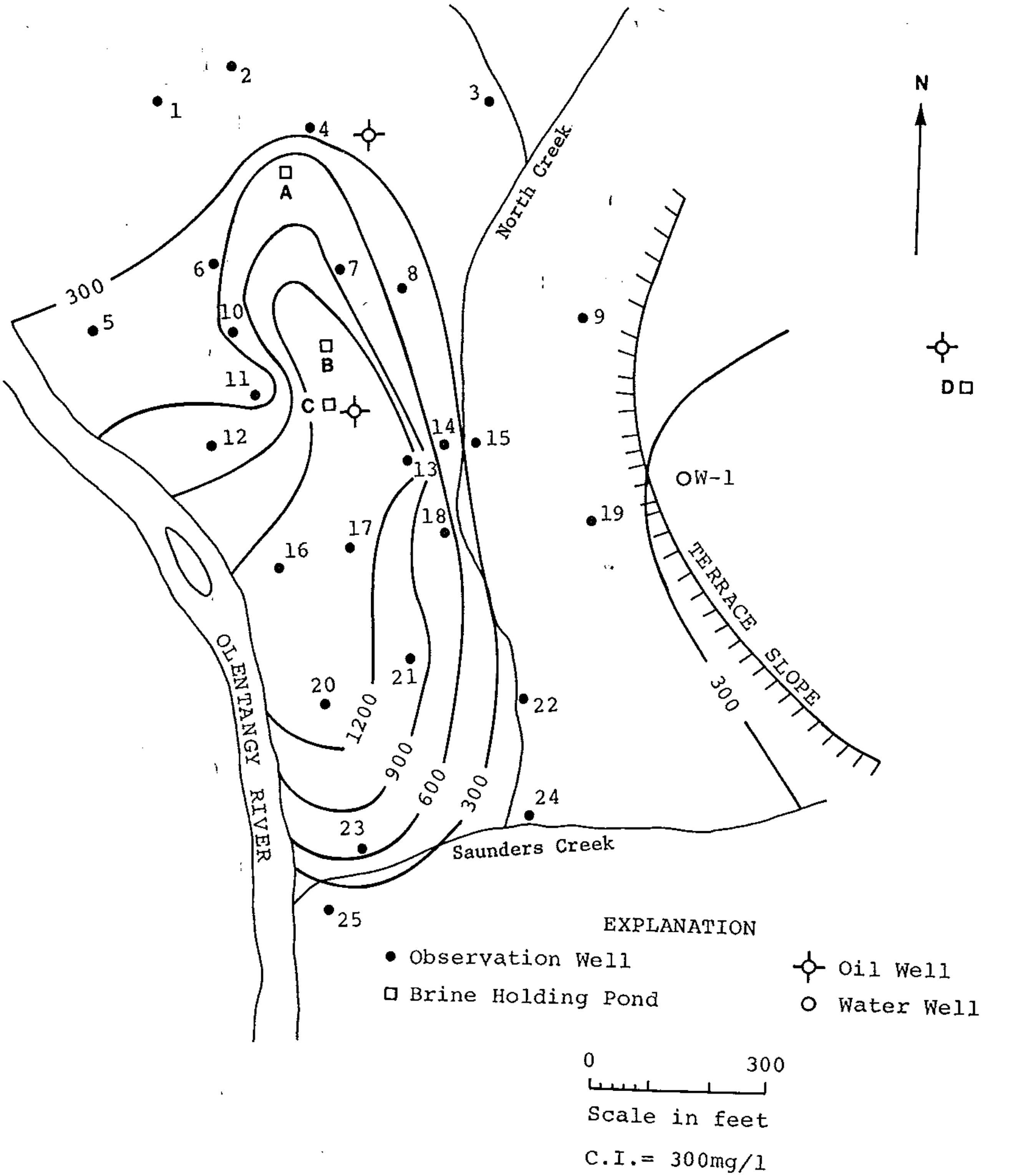


FIGURE III-5.3 Map showing groundwater isochlors in March 1969.

Figures III-5.4 and III-5.5 illustrate the construction details of three wells and the changes in chloride concentration during 1969 in these wells, which are in the vicinity of well 2, but are not shown on Figure III-5.1. Well D-17s is 9 ft deep; wells D-3 and D-16s are 25 ft deep. Well D-17s samples the water quality that exists 8 to 9 ft below the surface; well D-16s represents the quality from the water table to a depth of 25 ft. Well D-3 samples the quality at a depth of 22 to 23 ft. In Figure III-5.5, note the change in chloride concentration with both depth and time during 1969.

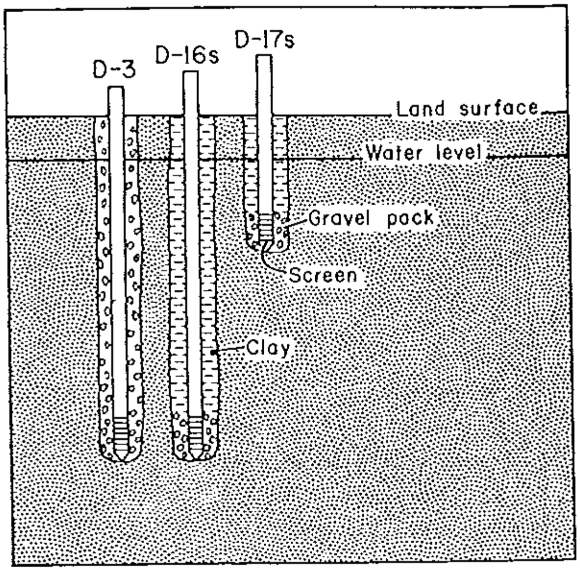


FIGURE III-5.4 Completion details of observation wells D-3, D-16s, and D-17s. (Pettyjohn, 1971, p. 267)

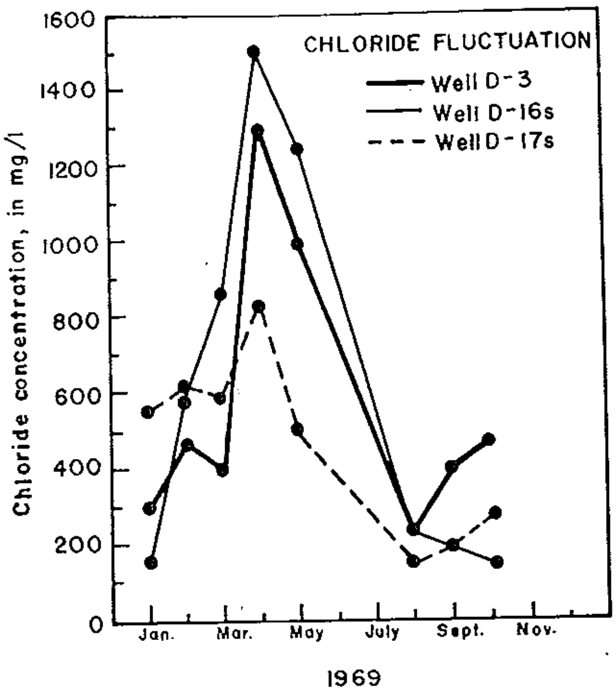
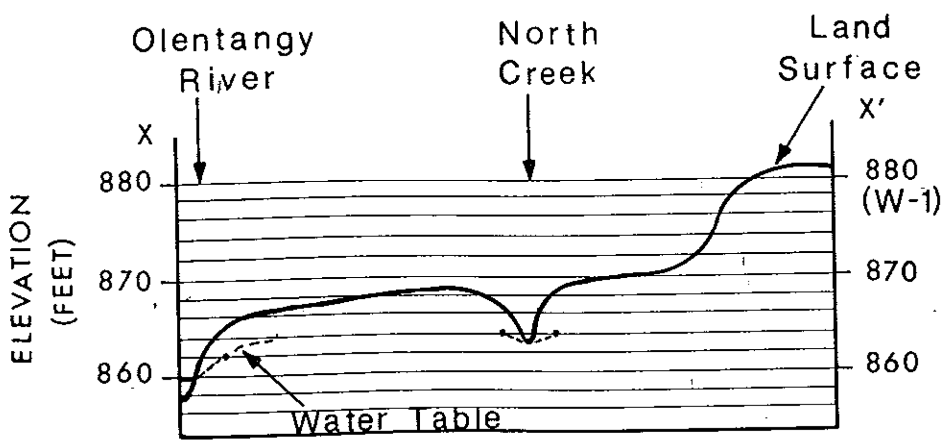


FIGURE III-5.5 Fluctuation of chloride content in wells D-3, D-16s, and D-17s during January–October 1969. (Pettyjohn, 1971, p. 267)

13. The shallow farm well (12 ft deep) at W-1 increased in chloride concentration between 1966 and 1969 (Table III-5.1). Has this contamination resulted from brine disposal into ponds A, B, C, or D? ________ Explain with the aid of a cross-section sketch (below) from X to X′ in Figure III-5.1.



Cross section X-X′ in Figure III-5.1.

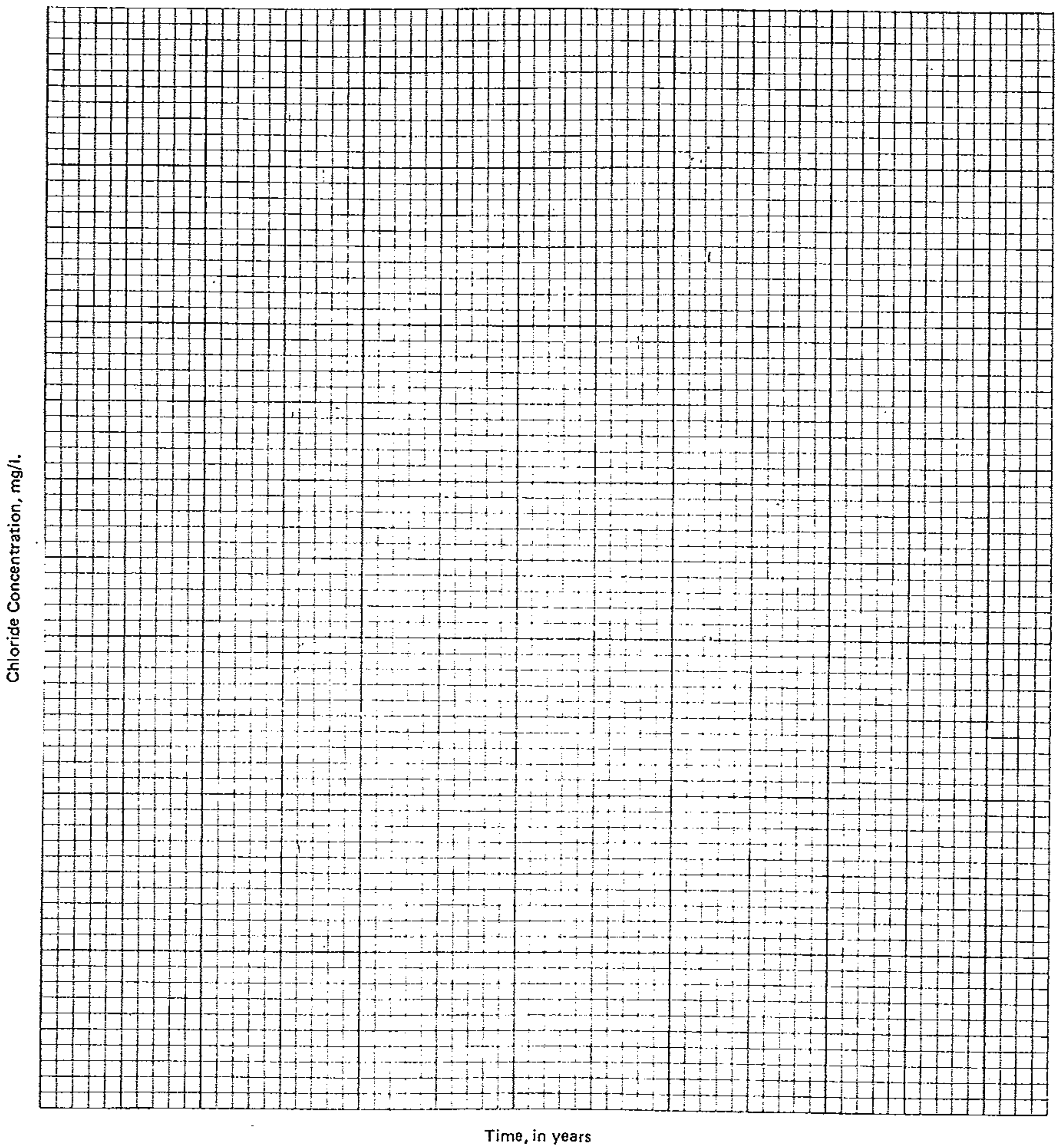


FIGURE III-5.6 ____________

14. Draw a graph showing the change in concentration of chloride over time in one or two wells. Use the graph paper provided in Figure III-5.6. Write a caption for the figure on the line provided. Then estimate, if possible, when the area will return to its original state.

15. What do Figures III-5.4 and III-5.5 indicate about the contamination of the alluvium?

16. Given the graph in Figure III-5.5, would you change your estimate in question 14?

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IV. GEOLOGIC RESOURCES

Exercise IV-1. Groundwater Overdraft and Saltwater Intrusion

INTRODUCTION

Offstream[1] water use in the United States is estimated to average 400 billion gal/day, with about 325 billion gal of this fresh water. Groundwater accounts for less than 25 percent of the total fresh water used, and untapped resources have great potential to meet future needs. Even though vast amounts of groundwater are available, in some areas pumping rates are such that water levels have declined hundreds of feet, wells have gone dry, the cost of pumping the water has increased substantially, and water of poor quality has been induced to flow into aquifers. Areas of large irrigation systems, such as that part of the Great Plains states underlain by the High Plains or Ogallala aquifer, exemplify the problems of groundwater overuse. Irrigation is the largest user of groundwater, although areas of dense population and heavy industry also consume large quantities.

Techniques have been devised to halt or reduce the water-level decline in some water-short areas. The most obvious method is to conserve water and reduce pumping. In other instances it may be possible to divert surface water, including treated wastewater, to infiltration basins, pits, or wells, which will allow the water to percolate into the ground at a rate that is considerably greater than that permitted by natural conditions. These techniques are collectively known as *artificial recharge* and have been used successfully throughout the world.

The overall objective of this exercise is to demonstrate the effects of overpumping groundwater reservoirs.

PART A. OVERUSE OF A GROUNDWATER RESOURCE: GRAND PRAIRIE REGION, ARKANSAS

The Grand Prairie region is in east-central Arkansas. This region is characterized by low relief which, in conjunction with an extensive aquifer and warm climate, provides an ideal setting for rice irrigation. Rice has been grown in this area since 1904. The configuration of the water level in 1915 is shown in Figure IV-1.1. Concentrated pumping of irrigation water from the underlying sandy aquifer has caused a substantial overdraft in the groundwater supply and a decline in water levels of several tens of feet. The objective of Part A of this exercise is to examine water-level and flowline changes associated with overpumping in the Grand Prairie region.

Banking institutions have made loans to rice farms in this area for many years. Because groundwater supplies play such an important role in rice production, the banks must stay informed of the availability of groundwater. As the water level declines, the cost of pumping the water increases. In the long run, pumping costs and other farm operating costs could be greater than the value of the crop. The economic impact of a declining water level is obvious.

In order to evaluate the rate and areal extent of water-level decline and to determine remedial measures, maps of conditions in 1915 and 1954 were prepared and evaluated.

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[1]Offstream use includes water from groundwater or surface-water sources for public water supply, agriculture, industrial, etc. use.

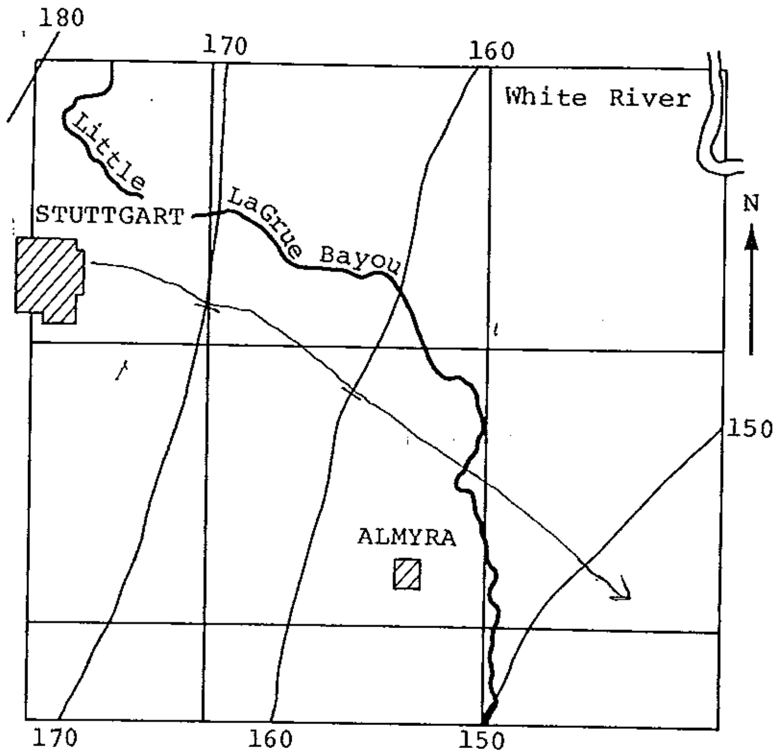

FIGURE IV-1.1 Altitude (in feet) of water level in Grand Prairie region in 1915. (Modified from Sniegocki, 1964)

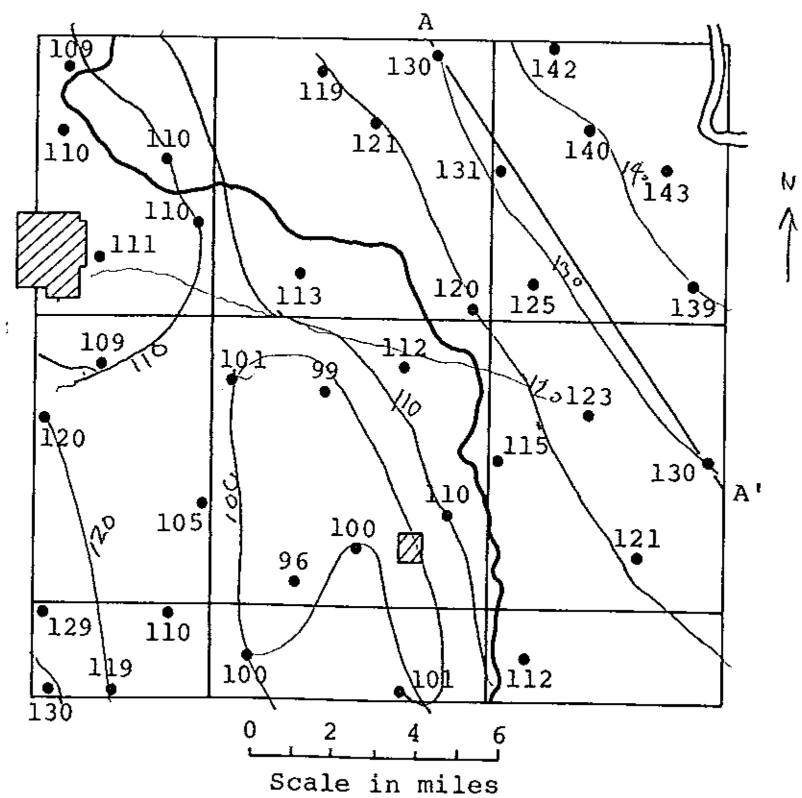

FIGURE IV-1.2 Altitude (in feet) of water level in Grand Prairie region in March 1954. (Data from Sniegocki, 1964)

QUESTIONS (IV-1, Part A)

1. a. On Figure IV-1.2 construct a map that shows the configuration of the water-level surface in March 1954, using a contour interval of 10 ft. Compare this map with Figure IV-1.1. What are the major differences? Groundwater Levels are depressed

   b. On Figure IV-1.3 construct a map that shows the net decline of water levels from 1915 to 1954. Use a contour interval of 10 ft. What area has had the greatest decrease in water levels? Buildup near Stuttgart

   c. Starting at the east edge of Stuttgart, draw a flowline across the 1915 map (Figure IV-1.1). Draw a similar flowline passing through Almyra. What was the general direction of groundwater movement in 1915 at

   Almyra? SE

   Stuttgart? E

   d. On Figure IV-1.2 draw the flowlines passing through Stuttgart and Almyra. What was the general direction of groundwater movement in 1954 near

   Almyra? S.E

   Stuttgart? E

2. Calculate the gradients that existed in 1915 and 1954 using the flowlines that pass through Almyra.

   a. Gradient in 1915: .09 x10⁻² god . 4%

   b. Gradient in 1954: .04 x 10⁻²

3. The permeability of the water-bearing deposits averages 2,000 gpd/ft², and the specific yield averages 17 percent. What was the groundwater velocity in 1954 in the vicinity of

   a. Stuttgart? $\frac{2000\ gpd/ft^2}{7.48}$ $\frac{.09 \times 10^{-2}}{.17}$ $\frac{180 \times 10^{-2}}{1.27}$ $\frac{1.80}{1.27}$ = 1.4 ft/day

   b. Almyra? $\frac{2000\ gpd/ft}{7.48}$ $\frac{.05 \times 10^{-2}}{.17}$ smaller

4. Assume that the saturated sand in the northeastern part of Figure IV-1.2 (along line A-A′) is 40 ft thick. How much groundwater, in gal/day, flowed across A-A′ during a single day in March 1954? .005
   Q = 2000 gpd/ft²
   40 ft x .005
   1.89 x 10⁸ gallons day
   25,344,600 cu ft day

5. Figure IV-1.3 indicates that there has been a significant lowering of water level. This means that more water is pumped from the aquifer than is flowing into it. This negative change in groundwater storage is termed *overdraft*. What could be done to decrease the rate of decline, maintain the existing level, or cause the water level to rise? Set up artificial recharge areas

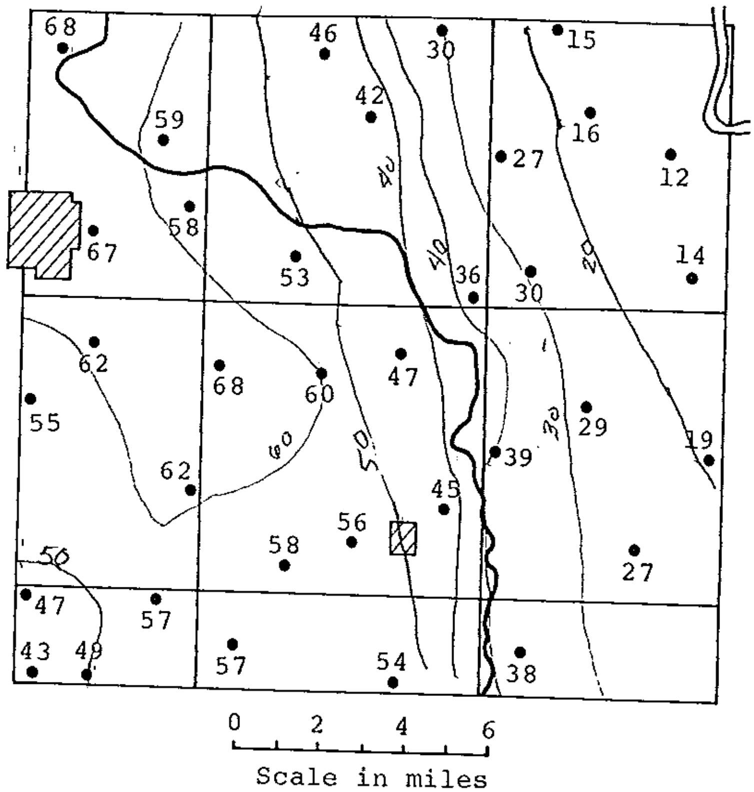

FIGURE IV-1.3 Net decline of water levels in the Grand Prairie region from 1915 to 1954. (Data from Sniegocki, 1964)

PART B. OVERUSE OF A GROUNDWATER RESOURCE: SALTWATER INTRUSION IN A COASTAL AQUIFER

The intrusion of saltwater into a fresh groundwater reservoir is surprisingly common throughout the world. Saltwater intrusion is generally caused by excessive pumping of groundwater and leads to deterioration of water quality. In inland areas it is caused by the upward movement of the fresh- and saltwater interface; in coastal regions it is commonly caused by both vertical and horizontal migration of sea water into a coastal aquifer.

Although geologic and hydrologic conditions may be exceedingly complex, the mechanics of saltwater intrusion may be visualized in the following manner. Assume that an aquifer crops out on the continental shelf and is hydrologically connected to the ocean. Normally, fresh water discharges from a coastal aquifer into the ocean along seepage faces or through springs (Figure IV-1.4A). As fresh water is pumped from the aquifer, the water pressure in the aquifer is lowered, reversing the hydraulic gradient (Figure IV-1.4B). With a reversal in gradient, sea water migrates inland and may eventually contaminate pumping wells.

Occurrences of saltwater intrusion are relatively common in coastal areas. Problem areas include much of the Atlantic coast from Florida to New England and many regions of the west coast where there are large withdrawals of groundwater.

Several techniques have been used to control saltwater intrusion. These include reducing the amount of pumping; constructing physical barriers, such as pumping cement into the rocks (Figure IV-1.4C); pumping wells nearer to the coast and allowing the water to flow back into the ocean (Figure IV-1.4D); and artificial recharge (Figure IV-1.4.E). The simplest solution is to reduce pumping, but commonly this is not feasible because of existing water demands. The most promising approaches are artificial recharge and water conservation. In the artificial recharge method, water is injected into the ground through pits and wells. This forms a hydraulic barrier (injection ridge) due to the higher water or water-pressure surface in the vicinity of the recharge sites, which lie between the well field and the coast (Figure IV-1.4E). The hydraulic barrier tends to reverse the water gradient and forces the saline water out of the aquifer.

In many coastal areas, saltwater intrusion has not yet occurred, but an examination of existing groundwater levels and pumping data indicates that there is a strong potential for future intrusion. If

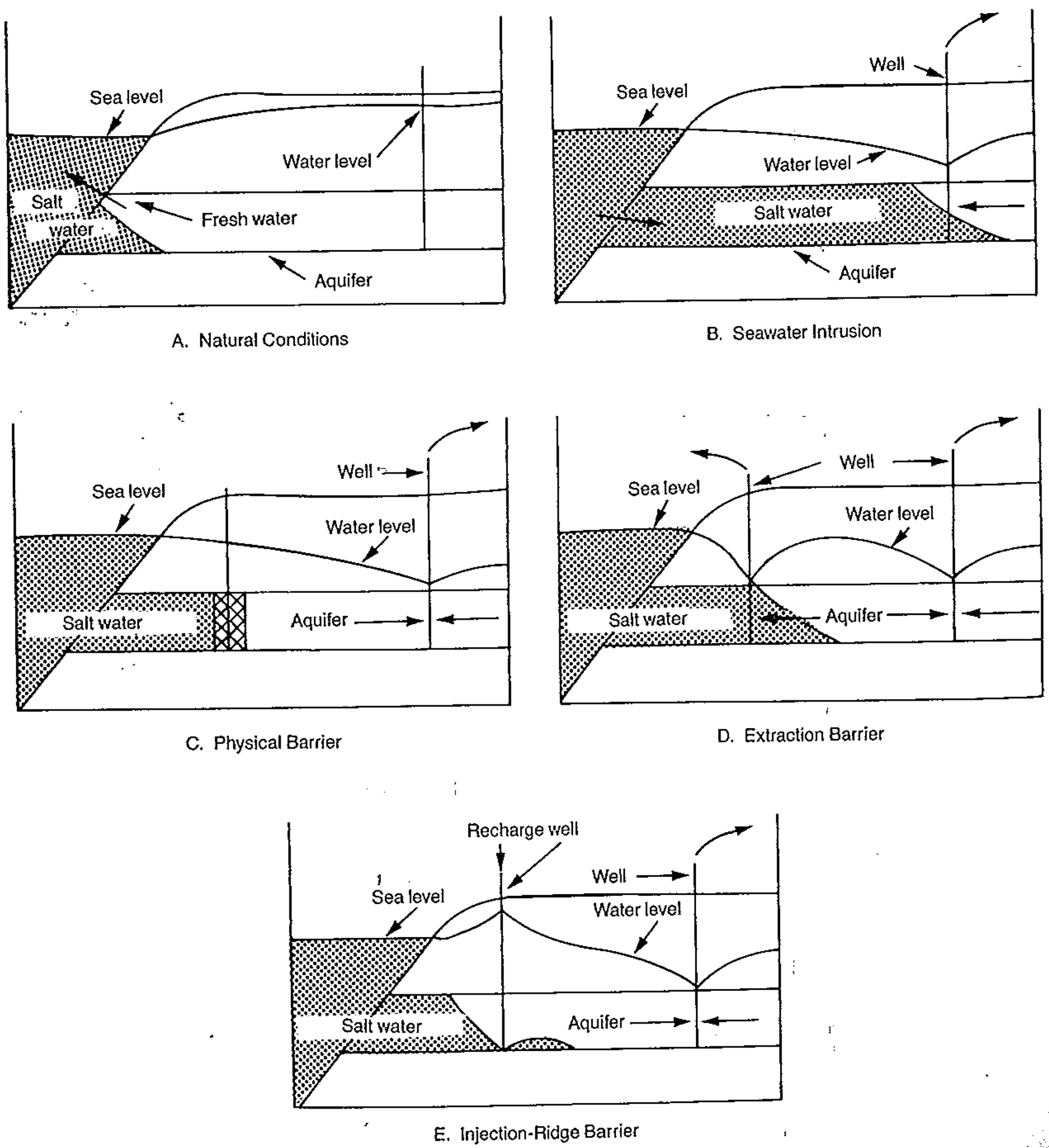

FIGURE IV-1.4 Saltwater intrusion of a coastal aquifer and the use of barriers to prevent contamination of water supplies. (See text for explanation of A through E.)

potential saltwater intrusion sites are analyzed before contamination actually occurs, it may be possible to develop adequate solutions before the supply situation becomes critical.

The objective of Part B of this exercise is to examine an area of potential saltwater intrusion and to briefly examine methods that could be used to halt the intrusion.

Potential Saltwater Intrusion in the Savannah Area

Large quantities of groundwater are used in the Savannah, Georgia, area for industrial, municipal, and domestic purposes. Over the years, water levels in wells have declined to more than 130 ft below land surface or more than 120 ft below sea level. This has caused concern that the water supply might become seriously depleted or contaminated. Most of the groundwater used in the Savannah area is pumped from a limestone aquifer that lies about 100 ft (northeast) to 350 ft (southwest) below land surface.

Although groundwater in the Savannah area has not yet become salty, the supply at Parris Island, about 25 miles northeast, has deteriorated due to saltwater intrusion. The pumping of groundwater in the Savannah area will no doubt increase and, as a result, intruding saltwater may eventually reach the pumping center and contaminate the water supply.

The Savannah River, which flows through the area, has been used as a partial source of water, but locally it is contaminated by industrial and municipal wastes. Furthermore, water can only be withdrawn from it at certain times because the river is influenced by tidal waters of high salinity.

QUESTIONS (IV -1, Part B)

1. A water-level map of the Savannah area representing conditions that existed in 1880 is shown in Figure IV-1.5. Construct four equally spaced flowlines showing the direction of ground-water movement in 1880. Remember that flowlines cross the water-pressure contours at right angles. What was the general direction of flow? E to W Was groundwater at Parris Island likely to have been salty in 1880? No Why? Withdrawl rate was low

2. Using Figure IV-1.6, construct a water-level map showing the conditions that existed in 1961. Use a contour interval of 10 ft.

3. Starting at the southwest and northwest corners of Figure IV-1.6, and at Parris Island, construct flowlines showing the general direction of groundwater movement in 1961. In what general direction was the water moving

   a. in the southwest corner? N

   b. in the northwest corner? Moving NW.

   c. at Parris Island? S.W.

4. From what area do you expect the fresh- and saltwater interface to first reach the Savannah area? ________ Why? (Hint: examine not only the water-level contours, but also consider the depth of the aquifer.) South of Hilton Head Area

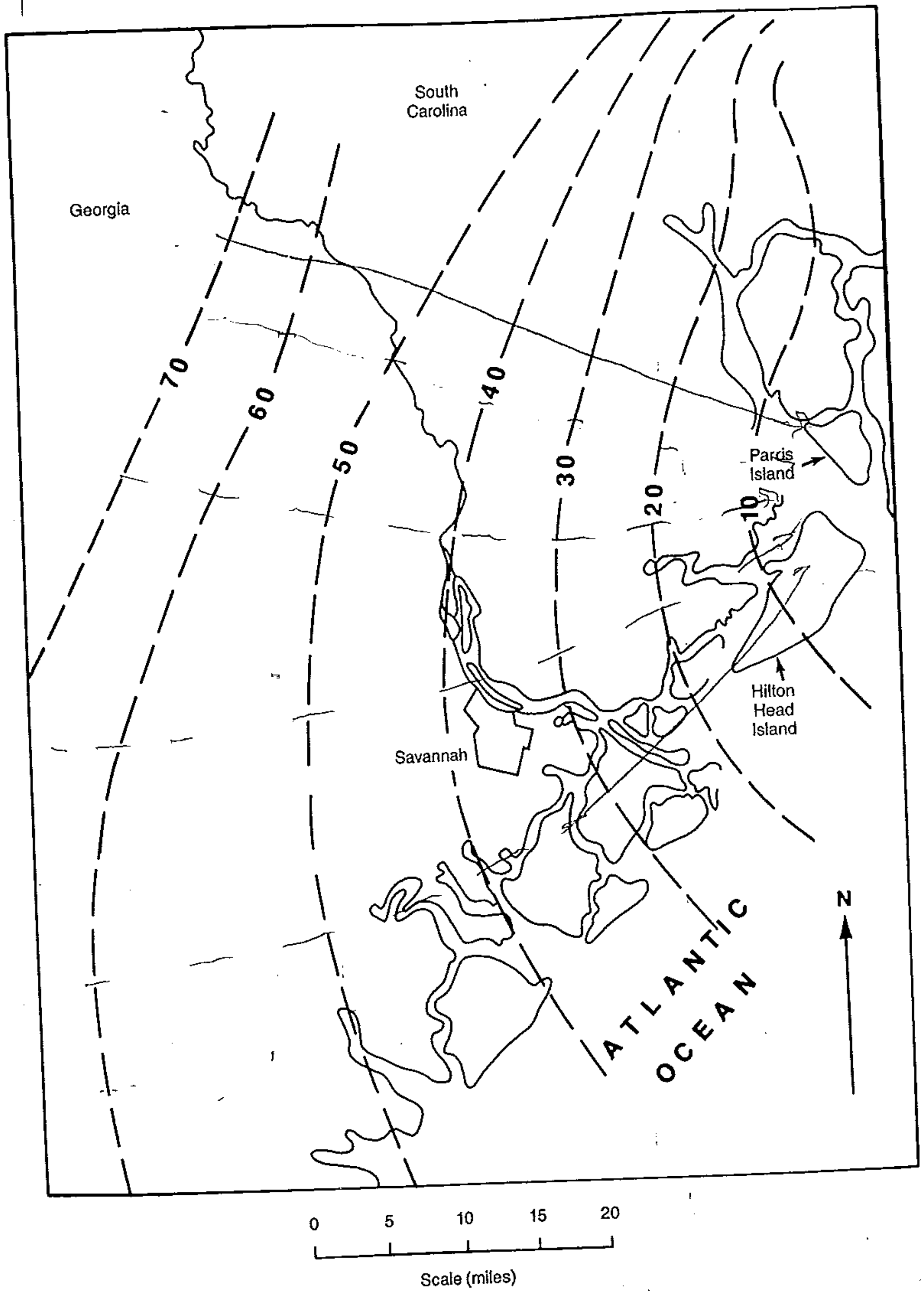

FIGURE IV-1.5 Altitude (in feet) of water level in the Savannah area in 1880. (Modified from Wait and Callahan, 1965)

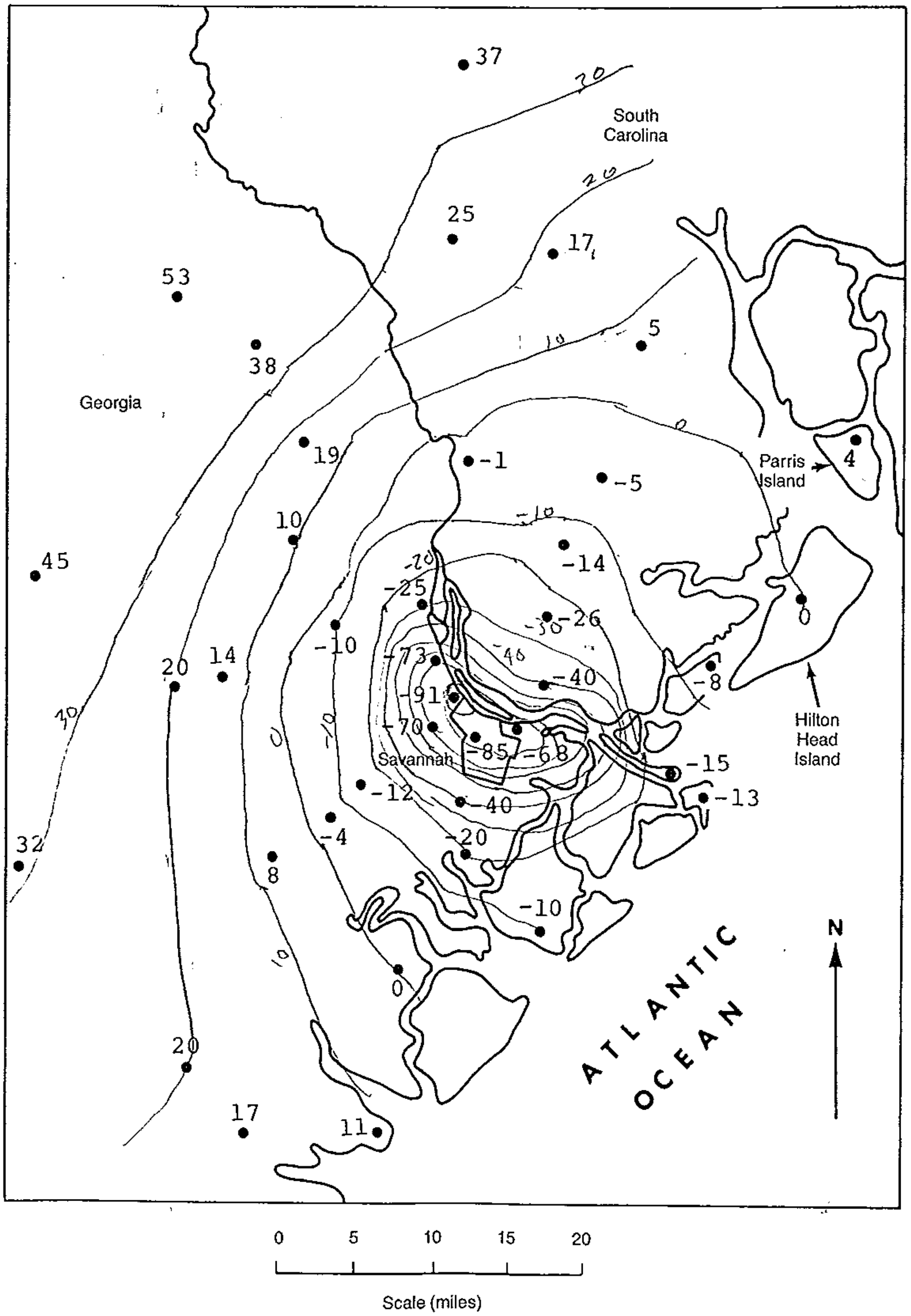

FIGURE IV-1.6 Altitude (in feet) of water level in the Savannah area in 1961. (Data from Wait and Callahan, 1965)

5. What techniques might be used to halt the groundwater decline and decrease the potential of saltwater intrusion into the area of extensive pumping at Savannah?

   1. Construct reservoirs
   2. Decrease pumping
   3. Construct artificial recharge canals of areas

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SECTION V

HOW GROUND WATER IS CONTAMINATED

SUMMARY

Innumerable waste materials and natural and man-made products, with the potential to contaminate ground water, are stored or disposed of on or beneath the land surface. Contaminants found in ground water cover the entire range of physical, inorganic chemical, organic chemical, bacteriological, and radioactive parameters.

Contaminants that have been introduced into ground water can move horizontally or vertically, depending on the comparative density and natural flow pattern of the water already contained in the aquifer. They tend to travel as a well-defined slug or plume but can be reduced in concentration with time and distance by such mechanisms as adsorption, ion exchange, dispersion, and decay. The rate of attenuation is a function of the type of contaminant and of the local hydrogeologic framework, but decades and even centuries are required for the process to be completely effective.

Under the right conditions and given enough time, contaminating fluids invading a body of natural ground water can move great distances, hidden from view and little changed in toxicity by the processes of attenuation. The eventual point of discharge of the contaminated ground-water body can be a well used as a drinking water source.

INTRODUCTION

The many and diverse activities of man produce innumerable waste materials and by-products; these are often deposited or stored on land surfaces where by percolation they may eventually be carried downward modifying the natural quality of the underlying ground water. Because of the large number of such locations, the sources and causes of ground-water contamination in the United States total in the millions. Fortunately, most are small sources whose contaminating effects are rapidly dissipated after they enter the ground. A few are widespread enough to affect large volumes of ground water.

The mechanisms of ground-water contamination are shown by illustrating the flow paths of contaminants for a variety of situations. The flow of ground water within underground formations affects the sizes and shapes of typical zones of contaminated ground water.

Ground-water contamination is the degradation of the natural quality of ground water as a result of man's activities. Contamination may impair the use of the water or may create hazards to public health through poisoning or the spread of disease. The term "contaminant" as defined in the Safe Drinking Water Act, means "any physical, chemical, biological, or radiological substance or matter in water."

Sources of contamination related to waste-disposal practices and described in detail in the following sections are:

1. Industrial Waste-Water Impoundments
2. Landfills and Dumps
3. Septic Tanks and Cesspools
4. Collection, Treatment, and Disposal of Municipal Waste Water
5. Land Spreading of Sludges
6. Brine Disposal from Petroleum Exploration and Development
7. Disposal of Mine Wastes
8. Disposal Wells
9. Disposal of Animal Feedlot Wastes

How contaminants from these waste disposal practices enter the hydrologic cycle via the ground-water system is illustrated in Figure 33.

MECHANISMS OF CONTAMINATION

If it were possible to see zones of ground-water contamination from an aerial vantage point, most would appear so small in relation to the total areas as to be termed scattered points of contamination. Areally extensive sources such as irrigation return flows and sea-water intrusion would be identified as non-point sources. A line source would result, for example, from recharge of sewage effluent in an ephemeral stream channel.

Shallow aquifers are normally the most important sources of ground water for water-supply purposes, but the upper por-

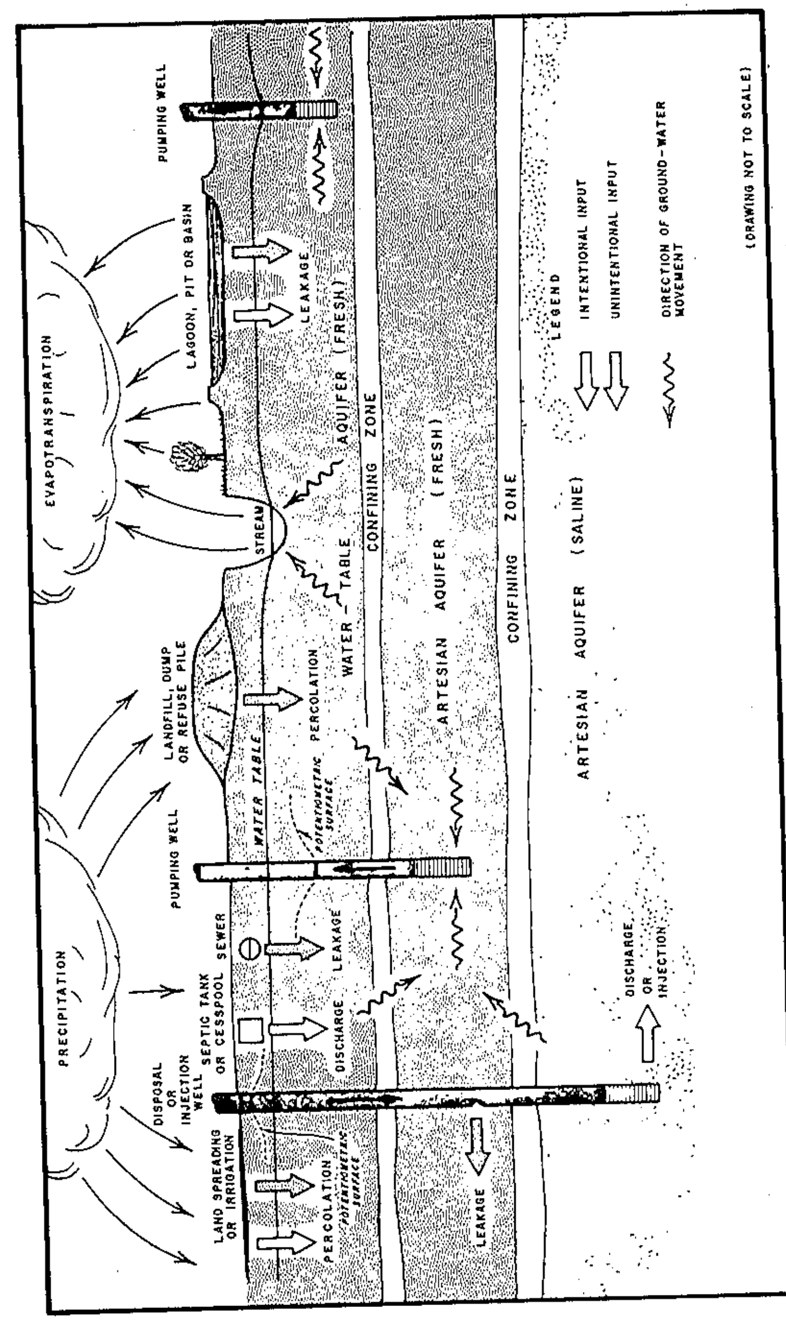

Figure 33. How waste disposal practices contaminate the ground-water system.

tions of these aquifers are also the most susceptible to contamination.

It should be recognized that the configuration of contamination entry into and movement within the underground is unique for each individual source of contamination. Furthermore, because there are many millions of ground-water contamination sources in the United States, it becomes apparent that the possibilities in terms of contaminant movement and distribution are virtually limitless. Notwithstanding this fact, typical flow patterns of ground-water contaminants for a variety of common situations can be described.

The diagrams on the following pages depict some of the frequently occurring contamination geometries. These emphasize vertical cross sections at sources of contamination; horizontal movement of contaminants thereafter is discussed later. Whatever the particular source of contamination may be, these diagrams indicate the hydraulic relationships for a given situation. Where the local hydrogeology is known, paths of probable contaminant movement can be defined. With estimates of permeability and hydraulic gradient available, rates of ground-water movement can be ascertained. Rates of contaminant movement are based on ground-water flow rates, chemical interactions with aquifer materials, and changes in water chemistry. Thus, contaminants travel at velocities equal to, greater than, or less than that of average ground-water flow.

Figure 34 illustrates the flow of contaminants from a surface source such as a disposal pit, lagoon, or basin. Note that the contaminated water flows downward to form a recharge mound at the water table and then moves laterally outward below the water table.

Figure 35 shows cross-sectional and plan views of ground-water contamination caused by a leaking sewer. The contaminant drains downward to the water table and then flows laterally thereafter to form a line source of contamination beneath the sewer.

Figure 36 indicates how contaminated water leached from a chemical or waste stockpile moves downward to the water table and thereafter laterally and vertically to a nearby pumping well.

Figure 37 indicates contaminant movement from a surface stream or lake to a nearby pumping well. The drawdown of the water table induces recharge of surface water to ground water. Because so many municipal water-supply wells are lo-

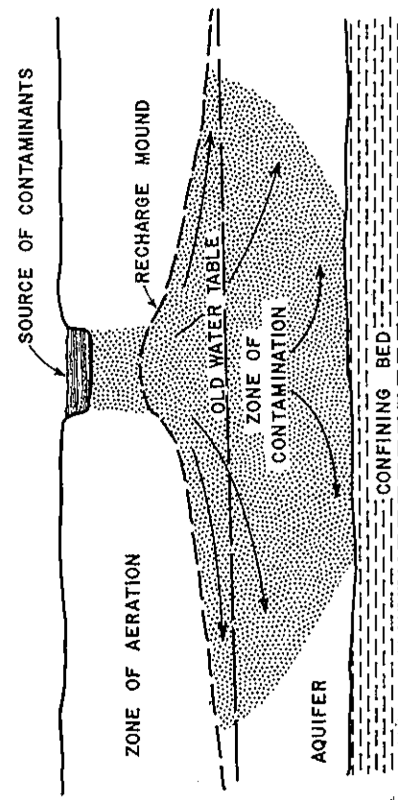

Figure 34. Diagram showing percolation of contaminants from a disposal pit to a water-table aquifer. (after 2)

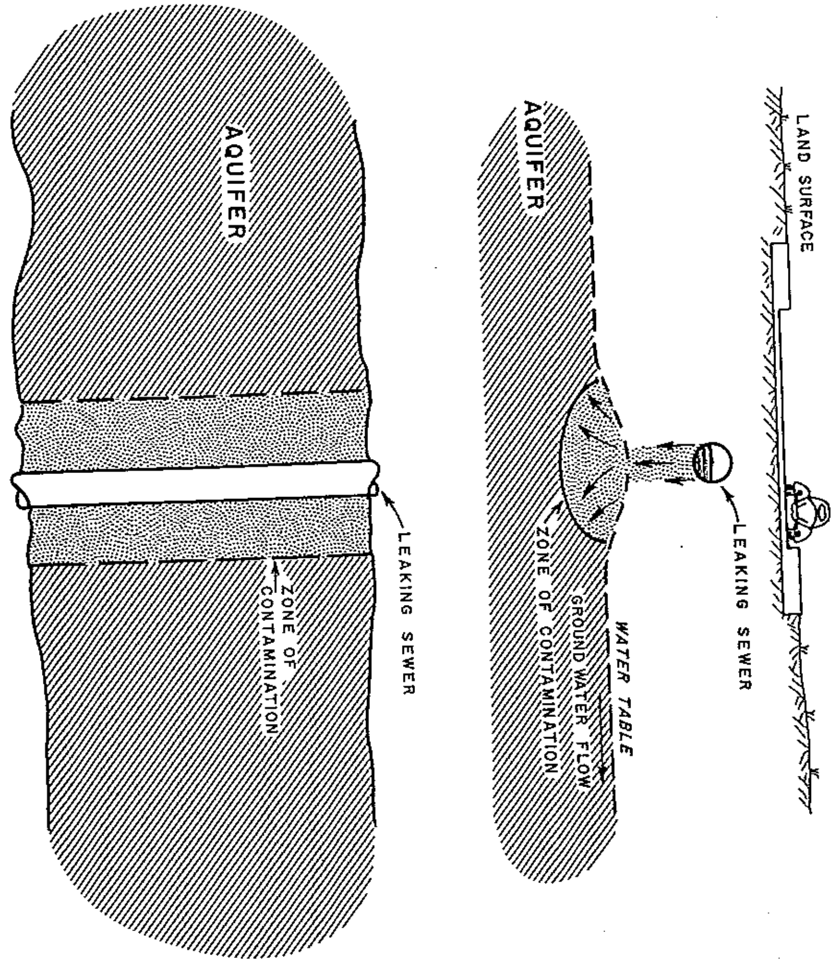

Figure 35. Illustration of a line source of ground-water contamination caused by a leaking sewer.

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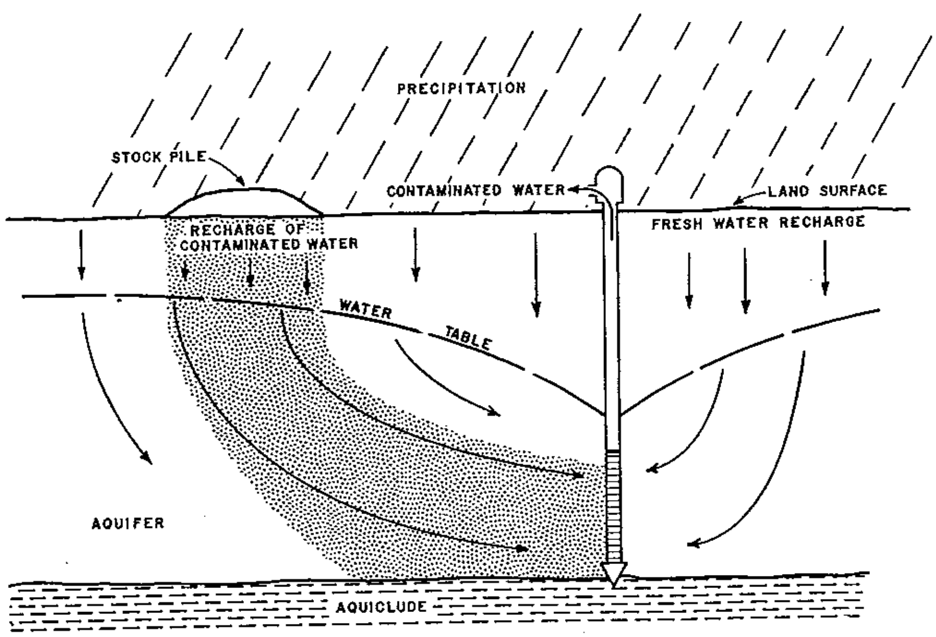

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Figure 36. Diagram showing contamination of an aquifer by leaching of surface solids.[2)]

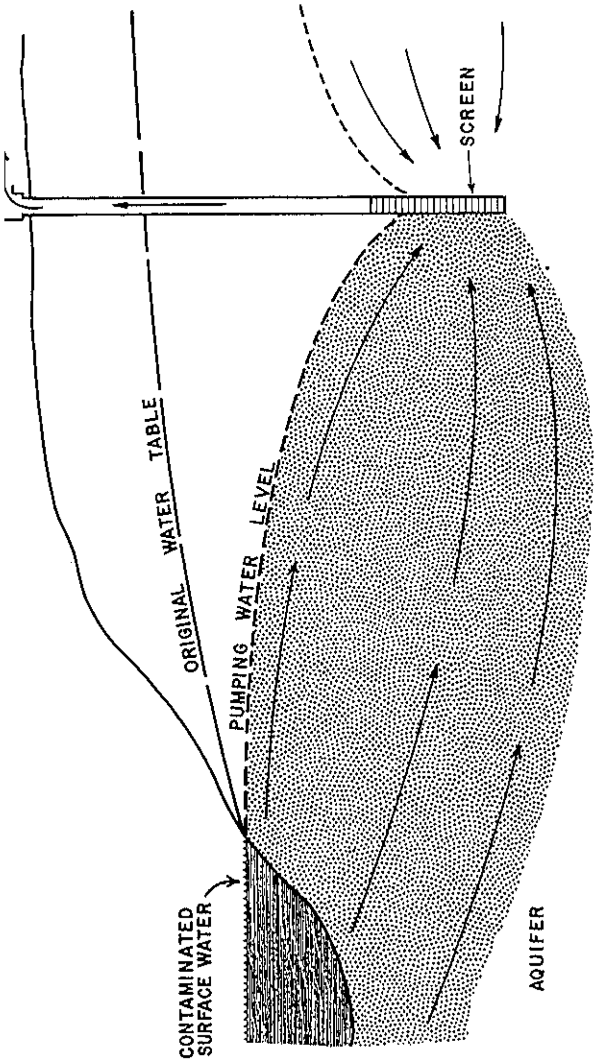

Figure 37. Diagram showing how contaminated water can be induced to flow from a surface stream to a well. 2)

cated adjacent to rivers in order to insure continuous water supplies, this is an important ground-water contamination mechanism where rivers are polluted.

Figure 38 suggests how temporary flooding of a well can lead to ground-water contamination. Downward flow of polluted surface water occurs around the well casing if the well has been improperly sealed at ground surface.

Figure 39 indicates how contaminants introduced into a disposal well can be transported through the aquifer and lead to contamination of a nearby pumping well. Because a pumping well is a convergence point for ground water over an area, this collection mechanism increases the opportunity for obtaining contaminated water from a pumping well.

Figure 40 illustrates the reversal of underground flows due to pumpage from one aquifer and hence the possibility to degrade the ground-water quality by interaquifer flow. Under natural conditions shown in the upper diagram, the water table of Aquifer A is higher than the potentiometric surface of Aquifer B; therefore, ground water tends to move downward through the semi-permeable zone separating the two aquifers. In the lower diagram, however, pumping has interchanged the relative positions of the two water levels. As a result, the greater pressure in Aquifer B causes water to migrate upward into Aquifer A. If, as is often the case, the lower aquifer is more saline, this will cause the salt content of the upper aquifer to increase.

Figure 41 shows plan and profile views of a recharge pond overlying an unconfined aquifer with a sloping water table and with ground water flowing from left to right. Under these conditions contamination from the pond extends a short distance upstream and is stabilized. The bulk of the contaminants moves away from the pond in a downgradient direction within clearly defined boundaries. For given aquifer and recharge conditions, the lateral spread of the contamination as it moves downstream can be determined. Waste water from a disposal well penetrating an aquifer having the same conditions would move in a similar flow pattern.

Figure 42 suggests how underlying saline ground water can rise due to deepening of a stream channel with a resultant lowering of the water table. This intrusion of saline water occurs because of the reduced head of fresh water.

ATTENUATION OF CONTAMINATION

Contaminants in ground water tend to be removed or reduced

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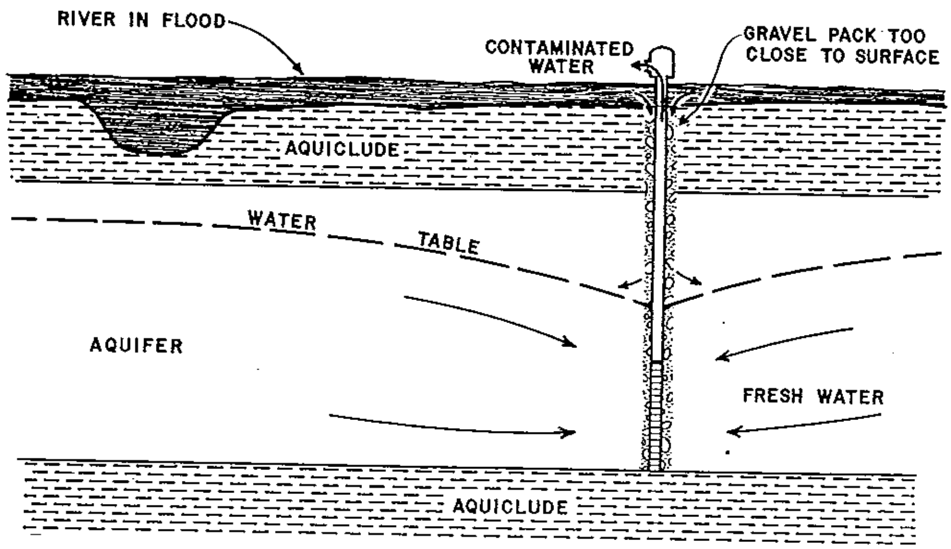

Figure 38. Diagram showing flood water entering a well through an improperly sealed gravel pack. 2)

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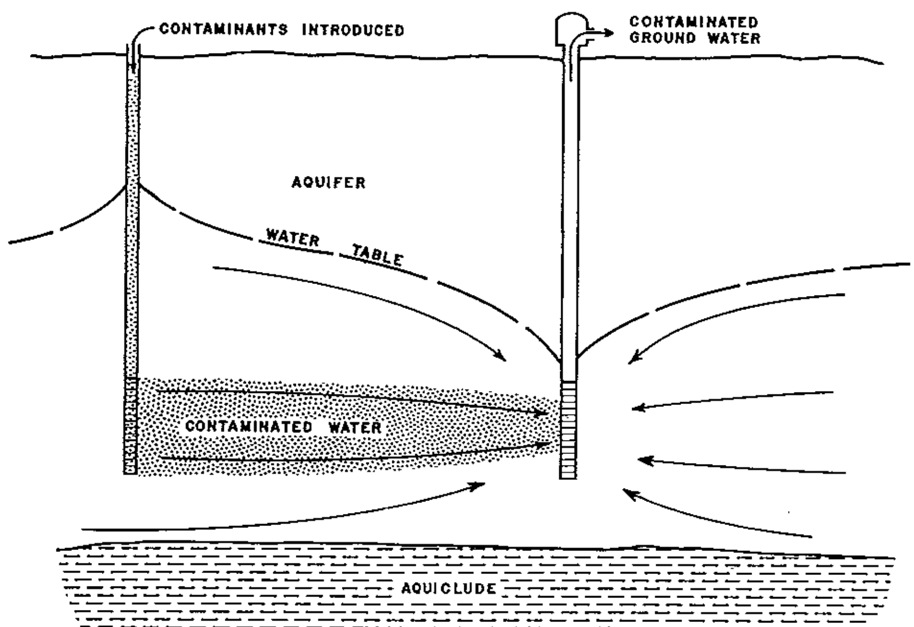
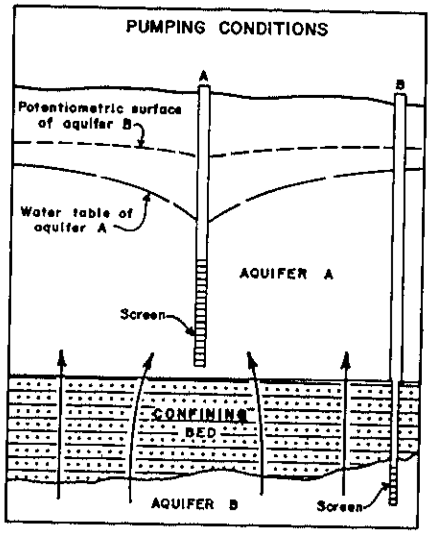


Figure 39. Diagram showing movement of contaminants from a recharge well to a nearby pumping well. 2)



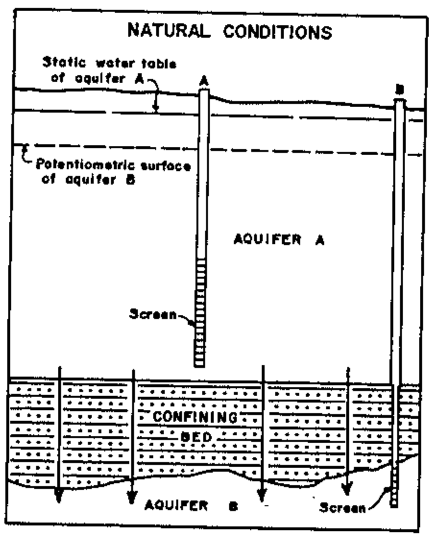


Figure 40. Diagrams showing reversal of aquifer leakage by pumping. 2)

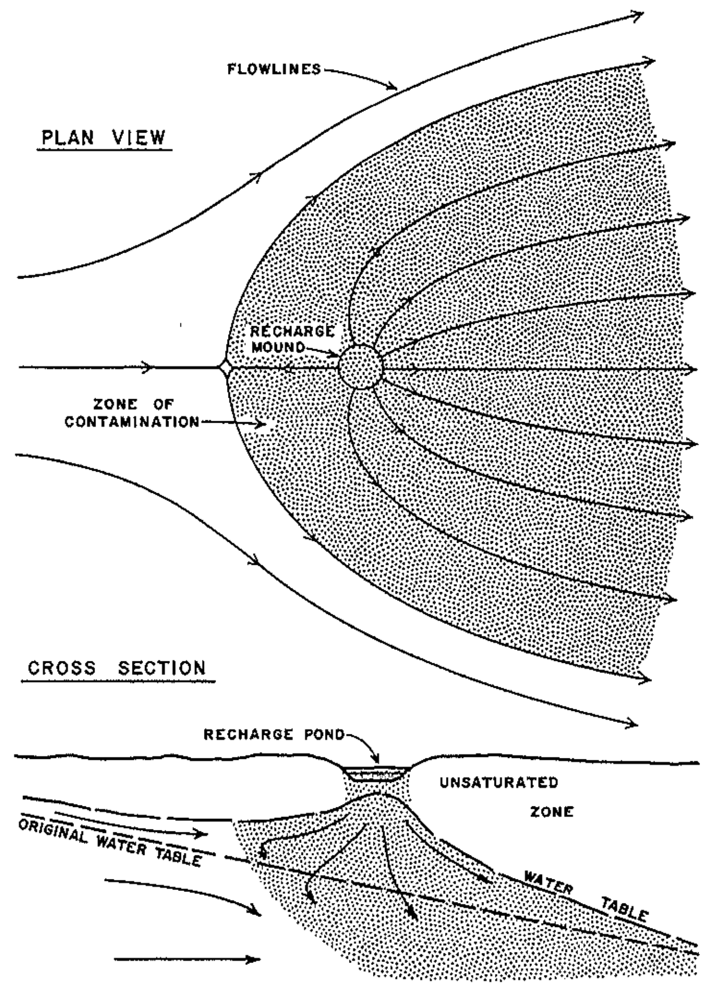


Figure 41. Diagrams showing lines of flow of contaminants from a recharge pond above a sloping water table. 2)

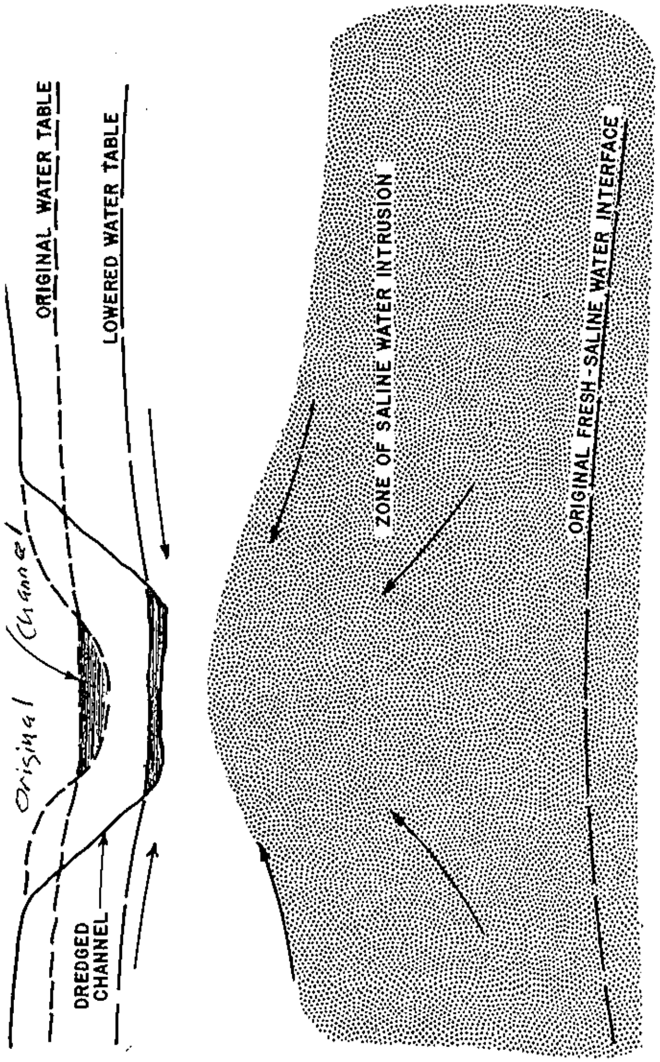


Figure 42. Diagram showing migration of saline water caused by lowering of water levels in a gaining stream. 2)

in concentration with time and with distance traveled. Mechanisms involved include adsorption and other chemical processes, dispersion and dilution, and decay. The rate of attenuation is a function of the type of contaminant and of the local hydrogeologic framework. Predicting the degree to which contaminants will become attenuated is one of the most difficult -- but also one of the most important -- problems in the design of subsurface waste disposal systems.

Adsorption

Adsorption, in the context of this report, is the phenomenon whereby the surfaces of solids in contact with water are covered with a thin layer of molecules or ions taken up from the water and held tightly by physical or chemical forces. The more finely divided the solid, the greater the surface area per unit volume, which is one of the reasons that clays and silts have greater adsorptive capacities than do sands. When all potential adsorption sites on a surface become occupied, the process becomes one of ion exchange. This is the case through much, or all, of the subsurface-water system.

Percolating water has four options in passing through the unsaturated zone. It can move virtually unchanged, can show a net gain of solute, show a net loss of solute, or keep the same total ionic concentration with a net exchange of ions. Since few soils or sediments are chemically inactive, changes in transported solute are to be expected.

Clay minerals carry a net negative charge on their surfaces. The amount of charge and surface area depends on the mineral type. The negatively charged points on the clay surface hold cations (which carry a positive charge) by electrostatic and van der Waals forces. Usually the attraction is proportional to the positive charge on the cation.

A quantitative exchange is usually observed in which two monovalent ions replace a divalent ion, etc. Heavy metal ions, for example, having more than one unit charge, are attracted to the exchange sites and tend to displace hydrogen, sodium, and potassium ions which are already adsorbed. A net reduction of heavy metal concentrations can occur in this way if percolating water contacts clay in the unsaturated zone. The limit for fixation is the cation exchange capacity (CEC) of the sediment, which can range from nearly zero to probably not more than 60 milliequivalents per 100 grams. When the saturation point is reached at which cations have occupied the available sites, the percolate composition will remain stable. Solution concentrations, pH, and percolation rate affect the reactions quantitatively;

thus, no quantitative predictions can be made without specific operating parameters.

Many soils and sediments have coatings of hydrous oxides of manganese and iron which exert controls on the availability of metal ions, and heavy metals in particular. 3) In fact, the hydrous oxide coating frequently covers clay-mineral surfaces and becomes the truly effective sorptive surface. These coatings exist in amorphous or microcrystalline forms and in themselves exhibit a high specific surface area; up to 300 square meters per gram. The oxygen and hydroxyl groups of the hydrous oxides exert electrical charges which are pH dependent. Therefore, their capacity for sorption is pH dependent.

The dissolution and deposition of the coatings are also dependent upon the oxidation-reduction (redox) potential in the system. This parameter then becomes indirectly important in the adsorption or desorption of heavy metals. Sorption and desorption of metals further depends upon their concentrations in the percolate and upon which ones are present. As with clays, there is an order of selectivity in adsorption. It is quite possible, however, that some heavy metals may move into the ground-water system prior to the exhaustion of exchange capacity.

Dispersion

An understanding of the flow pattern of contaminants is of considerable importance to the understanding of dispersion, and indeed of the entire ground-water contamination picture. Figure 43 illustrates an idealized flow pattern. From this it is seen that the contaminated water moves to its discharge area by a definite route, and is not (as is often imagined) subject to dilution by the entire body of ground water lying between the disposal area and the area of discharge. There is, however, dilution caused by mechanical dispersion, which results from the complexity (on a microscopic level) of the paths followed by the fluid, and (on a macroscopic level) inhomogeneities within the aquifer. Because of this, the contaminated fluid invades the natural ground water to some extent and is concurrently invaded by the latter. Molecular diffusion also takes place, but this is relatively unimportant except when the flow rate of ground water is very low, or the concentration of the contaminant is very high. The latter is associated with high density percolates, which will also distort the idealized pattern by tending to sink to the bottom of the aquifer.

Two related parameters are commonly used in dispersion stud-

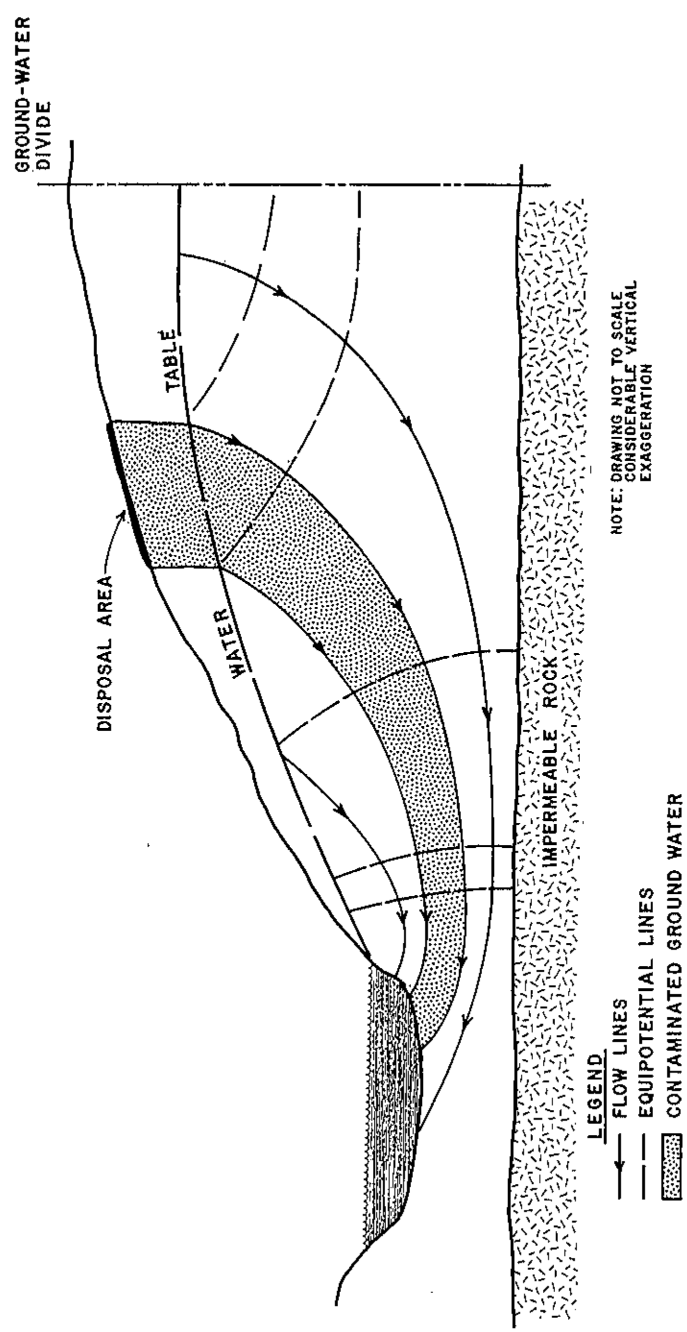


Figure 43. Flow in a water-table aquifer (humid region).

ies. The first, dispersivity, may be described as the inherent capability of the aquifer to cause dispersion. Dispersivity multiplied by ground-water flow velocity gives the dispersion coefficient, which is the dynamic equivalent under actual aquifer conditions. Both are given for longitudinal (in the direction of ground-water flow) and transverse directions.

The rate of ground-water movement within an aquifer is obviously of great importance. It is governed by the hydraulic gradient and aquifer permeability, the latter of which varies far more widely than any other physical property encountered in contamination studies. The U. S. Geological Survey 4) has determined permeabilities for a gravel through which, under a gradient of 10 ft/mi (2 m/km), water would move at the rate of 60 ft/day (18 m/day), and for a clay through which, under the same gradient, the rate of movement would be one ft (0.3 m) in about 30,000 years. Flow rates in most aquifers, however, range from a few feet per day to a few feet per year.

Theoretical solutions are available for the expression of dispersion phenomena. In digital models, these are usually combined with terms for molecular diffusion and adsorption isotherms. Unfortunately, these solutions are either restricted to relatively uncomplicated systems quite unlike those encountered in actual aquifers, or require the input of years of accumulated data to develop the values of otherwise undeterminable parameters. Mechanical dispersion, which is usually predominant in determining the shape of the plume of contamination, is so profoundly affected by heterogeneity that any attempt at detailed prediction is futile. Skibitzke 5) comments that "....the nature of the heterogeneous region can hardly be described through reference to the individual geometric discontinuities. Such a description would require an endless compendium of individual descriptions, a device so obviously impractical that it renders the region not amenable to description by measurement of any of the characteristics visible or accessible from the surface of the region."

One of the most informative studies on the spread of ground-water contamination, and the modeling thereof, is that carried out at the Idaho National Engineering Laboratory (INEL) and reported by Robertson and Barraclough 6), with additional background material in a report by Robertson, Schoen, and Barraclough. 7) Their findings show the state of the art of digital modeling for such purposes, and demonstrate clearly both the powers and the limitations of the method. The following discussion is directed to these ends, and technical details are limited to those necessary for a proper understanding.

The INEL site is on the Snake River Plain in southeast Idah overlying an aquifer consisting of thin basaltic flows and interbedded sediments, with a water table about 450 ft (137 m) below land surface. Industrial and low-level radioactiv wastes have been discharged to the aquifer through seepage ponds since 1952, and since 1964 cooling tower blowdown has been injected directly into the aquifer through an injectio well. The U. S. Geological Survey has monitored the facili ties since their inception, and has analyzed the fate of th wastes, using data from about 40 observation wells. The co plexity of the subsurface regime, however, is such that no explanation could be given for past behavior, and no predic tions could be made about the future. To resolve these que tions a digital model, simulating the aquifer, was develope The modeling included a hydrology phase to solve the equation for ground-water flow, and a solute-transport phase to solve the equation for solute movement, both of which were verified on the basis of historical behavior. The verifica tion procedure is used to adjust the values of various para eters, and Robertson and Barraclough note that the most spe ulative of these are the dispersivities and distribution coefficients, remarking that there is no effective and practical way of measuring coefficients in the field because of the large-scale aquifer inhomogeneities, and that it is therefore invalid to extend ordinary laboratory measurements to field conditions.

Simulations were made for chloride, a conservative ion; trit ium, which is subject to radioactive decay; and strontium-90, which is strongly adsorbed. It was concluded that the model is a valid tool for estimating waste distribution in the aquifer. Even so, the authors warn that this is highly dependent upon future hydrologic conditions, which can only be assumed.

Note that this model (which still provides only a fair to good approximation) required the input of 20 years of data from about 40 observation wells. It would not have been possible to predict the shape and extent of the plumes *a priori* by means of this or any other model.

The transverse dispersivity value (450 ft or 137 m) require to give the best fit of the theoretical plume to the observed plume is much larger than had been expected from either classic theory or laboratory models. The actual chlo ride plume, after 16 years, extended about 5 mi (8 km) downgradient and had a maximum width of almost 6 mi (10 km). In contrast, Pinder 8) found a transverse dispersivity value of only 14 ft (4.3 m) in a case of chromium contamination in a glacial aquifer on Long Island. The shapes of the two types of plumes are shown in Figure 44. In this particular case, the shape of the plume of contamination could have been predicted with moderate accuracy from the time that contamination commenced, since the aquifer is fairly homogeneous in two dimensions. Drawing a three degree cone, as suggested by Danel (quoted by Todd 9)), along the flow lines, using the mound formed under the disposal ponds as an apex, gives nearly as good a fit as does the digital model. This approach does not, of course, involve the element of time. For practical purposes, however, it could be applied to similar aquifers to provide a general idea of what the area of contamination would be, but this by no means would eliminate the need for monitoring and periodic analysis of collected data.

Radioactive Decay 10)

Radioactive isotopes may be defined as forms of atoms that with the re- are characterized by spontaneous disintegration, lease of energy. Some occur in nature (e.g., the isotopes of uranium), while hundreds more have been produced artifi- cially. At least one radioactive isotope is known for every element. All of the radioactive and stable isotopes of an element are indistinguishable by chemical means, since they have the same atomic number. The differences are in the mass of the atomic nucleus, and the isotopes are identified by this mass number, as carbon-12 and carbon-14.

Radioactive contaminants of concern to ground-water systems can include waste materials produced from a variety of commercial and governmental activities. Both naturally occurring and so-called artificial or man-made radionuclides are included. By-products and wastes from uranium mining and milling activities contain uranium decay products, for example, which can enter ground-water systems. Ground-water contamination has occurred in conjunction with storage and disposal of nuclear fuel cycle wastes, including high-level liquid wastes leaking from steel tanks into the ground. The foremost example of this occurred at Hanford, Washington. Radioactive contaminants lose their radioactivity at a fixed and unalterable rate that is characteristic of the isotopes involved. This decay rate is expressed in terms of half-life, which is the time lapse required for the loss (per unit mass) of half the radioactivity. Half-lives range from fractions of a second to millions of years; but those of the isotopes of principal concern in ground-water contamination are mostly in the range of tens to thousands of years.

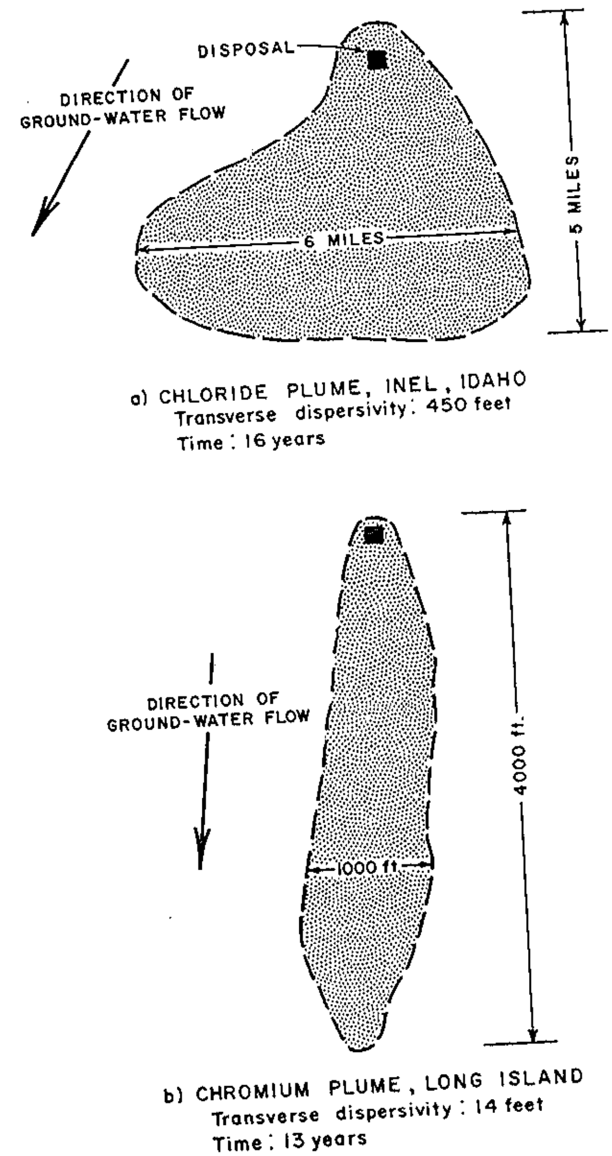


Figure 44. Effect of differences in transverse dispersivity on shapes of contamination plumes.

Strontium-90, for example, has a half-life of about 28 years.

Many radioisotopes are members of radioactive decay chains or series wherein the daughters produced by decay are themselves radioactive. One example is the decay of strontium-90 to form yttrium-90, with a half-life of about 62 hours, which in turn decays to the stable zirconium-90. Thus, at any moment, all three isotopes will be present in any media containing strontium-90. Similarly, uranium-238 passes through 14 states of decay before arriving at lead-206, the stable end product.

In considering the rate of movement of radwaste materials into and through ground-water systems, the effects of radioactive decay, dispersion, and adsorption must be considered together. Within the ground-water system, the other mechanisms may be more effective than decay in reduction of radioactive contamination. For example, field data from the Idaho National Engineering Laboratory show a very small plume of strontium-90 as compared with tritium, from radioactive wastes which had entered the ground from various disposal operations. Because strontium-90 has a half-life over twice as long as tritium (28 years versus 12 years), one might expect the strontium to have migrated further than the tritium. The reason for the discrepancy is that strontium-90 is strongly adsorbed in the subsurface while tritium is not adsorbed at all.

Adverse water quality impacts from radionuclides are dependent upon numerous factors, chief of which are concentration, half-life, toxicity, hydrogeologic conditions, and biologic receptors (plants, animals, man). Attenuation in the environment also is dependent upon these factors, which must be mutually considered in evaluating the hazard of a given situation involving radioactive contaminants in ground water.

DISTRIBUTION OF CONTAMINATION UNDERGROUND

Specific statements cannot be made about the distances that contamination will travel because of the wide variability of aquifer conditions and types of contaminants. Also, each constituent from a source of contamination may follow a different attenuation rate, and the distance to which contamination is present will vary with each quality component. Yet certain generalizations which are widely applicable can be stated. For fine-grained alluvial aquifers, contaminants such as bacteria, viruses, organic materials, pesticides, and most radioactive materials, are usually removed by adsorption within distances of less than 328 ft (100 m). But most common ions in solution move unimpeded through these

aquifers, subject only to the slow processes of attenuation.

A hypothetical example of a waste-disposal site is shown in Figure 45. Here ground water flows toward a river. Zones A, B, C, D, and E represent essentially stable limits for different contaminants resulting from the steady release of liquid wastes of unchanging composition. Contaminants form a plume of contaminated water extending downgradient from the contamination source until they attenuate to acceptable quality levels.

The shape and size of a plume depend upon the local geology, the ground-water flow, the type and concentration of contaminants, the continuity of waste disposal, and any modifications of the ground-water system by man, such as well pumping. 1) Where ground water is moving relatively rapidly, a plume from a point source will tend to be long and thin; but where the flow rate is low, the contaminant will tend to spread more laterally to form a somewhat wider plume. Irregular plumes can be created by local influences such as pumping wells and variations in permeability.

Plumes ordinarily tend to become stable in areas where there is a constant input of waste into the ground. This occurs for one of two reasons: (a) the tendency for enlargement as contaminants continue to be added at a point source is counterbalanced by the combined attenuation mechanisms, or (b) the contaminant reaches a location of ground-water discharge, such as a stream, and emerges from the underground. When a waste is first released into ground water, the plume expands until a quasi-equilibrium stage is reached. If sorption is important, a steady inflow of contamination will cause a slow expansion of the plume as the earth materials within it reach a sorption capability limit.

An approximately stable plume will expand or contract generally in response to changes in the rate of waste discharge. Figure 46 shows changes in plumes that can be anticipated from variations in waste inputs.

An important aspect of ground-water contamination is the fact that it may persist underground for years, decades, or even centuries. This is in marked contrast to surface-water pollution. The average residence time of ground water is on the order of 200 years; consequently, a contaminant which is not readily decayed or sorbed underground can remain as a degrading influence on the resource for indefinite periods. But the comparable residence time for water in a stream or river is on the order of 10 days; thus, contamination can be rapidly eliminated. Controlling ground-water contamination,

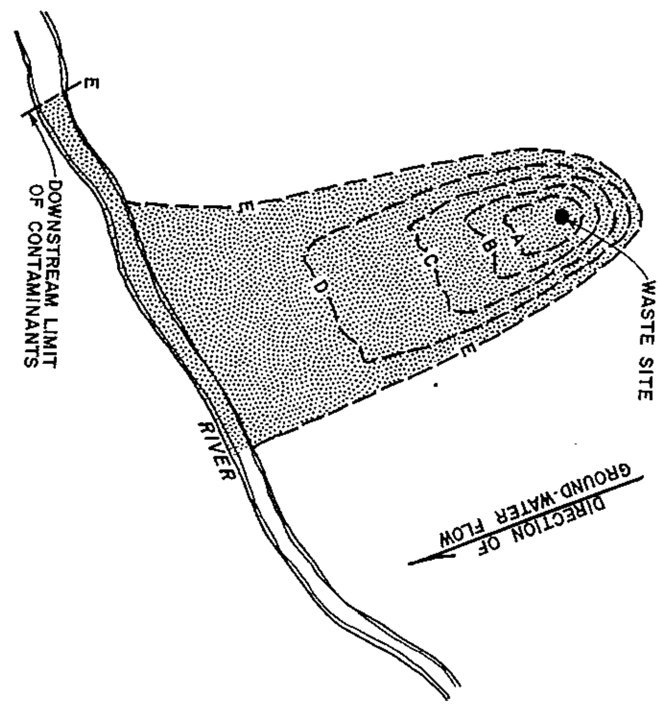


Figure 45. Plan view of a water-table aquifer showing the hypothetical areal extent to which specific contaminants of mixed wastes at a disposal site disperse and move. 1)

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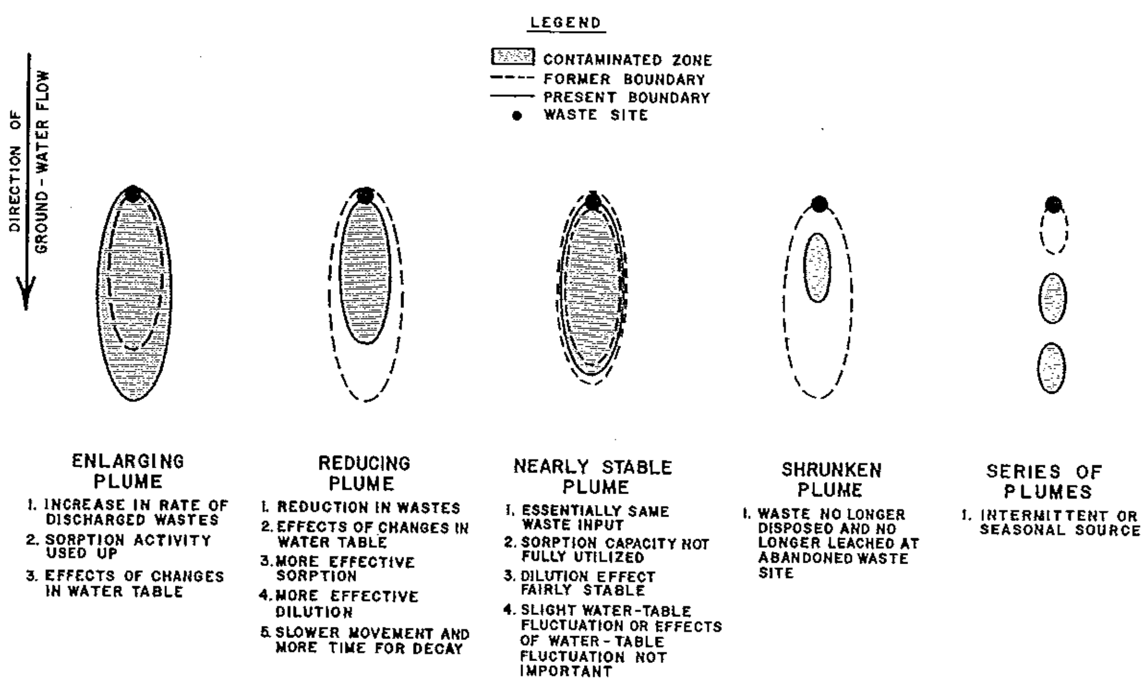

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Figure 46. Changes in plumes and factors causing the changes. after 1)

therefore, is usually much more difficult than controlling surface-water contamination. Underground contamination control is best achieved by regulating the source of contamination, and secondarily by physically entrapping and, when feasible, removing the contaminated water from the underground.

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