HYDROLOGIC IMPLICATIONS OF COAL MINING
IN THE NARRAGANSETT BASIN, RHODE ISLAND

by

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FOREWORD

This study is a part of a larger University of Rhode Island team effort to develop a State program for the regulation of environmental impact of coal mining in Rhode Island. The study was coordinated by the University of Rhode Island Energy Center in conjunction with the Rhode Island Department of Environmental Management. Funding support was provided by the U.S. Office of Surface Mining under OSM/DEM Grant no. 539928. Major assistance during the course of this study was provided to the Providence Office of the U.S. Geological Survey and the many city and town water supply agencies. Technical dissemination of this document is provided by the Rhode Island Water Resources Center at the University of Rhode Island.
HYDROLOGIC IMPLICATIONS OF COAL MINING
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ABSTRACT

Geologic exploration of the Narragansett Basin has resulted in estimates of 17 million tons of anthracite coal in the Portsmouth, Rhode Island area alone. Additionally coal seams have been found in several other parts of the Basin. The hydrologic implications of coal mining are of great importance because of the high density of population in the coal mining regions. While most of the area is serviced by public water supply systems not likely to be affected by coal mining, smaller surface and ground water sources are highly vulnerable and could be adversely affected.

Hydrologic implications of mining can include disruption of drainage patterns, lowering of the ground water table, diminishing of stream flow, degradation of water quality and inducement of salt water intrusion. Because of the potential irreparable harm that can be done, careful planning by state and municipal agencies is essential in advance of any mining operations. The collection of base line data prior to mining operations, and monitoring during and after mining is critical to avoiding adverse environmental impact.

Mining operations have a potential for direct degradation of surface water. Suspended sediment from coal processing and surface erosion must be controlled. Acid mine drainage is possible, but not likely because of the lack of framoidal pyrite in the Narragansett Basin rocks; however, site specific investigation and predictions should be made.

In the coastal regions of the Narragansett Basin, lowering of the water table by mine dewatering could cause salt water intrusion with severe consequences to wells in the affected area. Since salt water
bodies exist within a few miles of any prospective mining operations, Rhode Island coal mining regulations should include specific provisions to guard against ground water contamination by salt water intrusion.
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HYDROLOGIC IMPLICATIONS OF COAL MINING
IN THE NARRAGANSETT BASIN, RHODE ISLAND

INTRODUCTION

PURPOSE

The purpose of this report is to evaluate the hydrologic implications of coal mining in the Rhode Island portion of the Narragansett basin. The scope includes a general discussion of the current hydrology and water use in the Basin as well as the implications of coal mining activity.

SIGNIFICANCE

Geologic exploration and evaluation of the Pennsylvanian sedimentary rocks of the 900 square mile Narragansett Basin (Fig. 1) has produced resource estimates of 17.08 million tons of anthracite material in the eastern and western part of the Portsmouth, Rhode Island area (Shehan et al., 1981). In addition, test holes have indicates coal seams in the Barrington area of Rhode Island (Frimpter and Maevsky, 1979). According to Shehan et al. (1981), the incompetency of the roof and floor rock would tend to preclude underground mining methods; however surface mining, such as the open pit method would be feasible. The significant implications of such mining to the hydrology of a region are:

A. disruption of surface water levels and drainage
B. disruption of groundwater levels and flow patterns
C. depletion or reduction of groundwater
D. inducement of salt water intrusion
E. degradation of water quality
PRESENTATION

This report discusses the hydrologic implications of coal mining in three main divisions. First the natural and existing conditions in the Narragansett Basin are presented, including the interrelation of surface and ground water as a part of the hydrologic cycle, and a description of existing water supply systems is included. Secondly the possible effects of mining on levels of surface water and groundwater, the potential for salt water intrusion and the degradation of water quality mine acid water and suspended sediment from mining excavations are considered. Lastly a review is made of applicable regulations and water law, and mine control recommendations are made.
CLIMATE

Average annual precipitation in the Narragansett basin, based on the period 1940-1956 is 42.7 inches (Lang, 1961). The average annual precipitation tends to be lower in the basin than in the rest of Rhode Island as shown in Figure 2. At all eight stations located in the basin, rainfall is fairly uniformly distributed throughout the year. November is normally the wettest month having a mean precipitation of 4.83 inches, and June is the driest month, having 2.56 inches. There is however, great variability evidenced in the record for individual months and years. As an example, June 1982, normally the driest month, had a record 14.35 inches of rainfall; the minimum is 0.04 for the Kingston station. Mean annual precipitation has ranged from 30.69 inches in 1965 to 76.22 inches in 1898 at Kingston, a station with 93 years of record.

The mean annual air temperature is slightly above 50°F, the regions nearest the water being somewhat moderated as compared to inland stations. The coldest month normally occurs in February with a mean temperature of about 29°F in the Upper Narragansett Bay region and the hottest in July with a mean of about 73°F. Extremes of record at Providence (T.F. Green Airport) range from -17°F to 102°F.

Water is lost to the atmosphere by evapotranspiration, a term combining evaporation from land and water surfaces, and the transpiration of plants. Evapotranspiration is largely controlled by air temperature. During the winter or the non-growing season when temperatures are low, evapotranspiration is very little. But as air temperature rises and the growing season starts, evapotranspiration increases rapidly, reaching a maximum in July or early August. Water loss by evapotranspiration in a
FIGURE 2. Average annual precipitation in Rhode Island (after Lang, 1961)
drainage basin is the difference between the precipitation over the basin and the runoff from the basin, including changes in surface and underground water storage for a given period. In humid regions a good estimate of annual evapotranspiration can be obtained by relation to average annual air temperature (Langbein et al., 1949). For the Narragansett basin the evapotranspiration thus obtained is 24 inches.

HYDROLOGIC CYCLE

Precipitation, evapotranspiration, groundwater and surface water are all interrelated in a complex dynamic system termed the hydrologic cycle. The hydrologic cycle is the circulation of water from the sea, through the atmosphere, and back to the sea by various overland and subterranean routes. This cycle is illustrated in Figure 3 for a coastal area. In evaluating the impact on any of the components on the hydrologic cycle, the interrelation of all others must be considered.

The interrelation can be illustrated by examination of the effect on groundwater recharge during a drought year, that is a year in which precipitation is 15% below normal. For the Narragansett basin this would be 36.3 inches of precipitation. Evapotranspiration would continue at about 24 inches, leaving only 12.3 inches for surface runoff and groundwater recharge as compared to a normal 18.7 inches. The most significant effect is likely to be on the groundwater levels, depending on the particular pattern of the drought. Additional stresses such as dewatering of mine excavations may greatly aggravate the effect on wells and diminished streamflow.
FIGURE 3. Hydrologic cycle and groundwater circulation (from Frimpter and Maevsky, 1979)
SURFACE WATER

An inventory of Rhode Island Lakes and Ponds (Wks, 1974) lists 357 fresh water impoundments. Of this an estimated 15 to 20% lie within the Narragansett basin. Most are relatively small, less than 50 acres in surface area. Many are an essential part of public water supply systems as will be discussed later. In general these water bodies are visible manifestations of the water table in the area, and are connected hydraulically to the groundwater. Therefore any effect on groundwater levels or quality may be important to ponds and lakes in the area and vice versa.

Innumerable streams flowing into the Bay drain the Narragansett Basin. The largest of these are in the upper basin area and include the Providence River formed by the confluence of the Woonasquatucket and Mohassuck Rivers, Blackstone River, Ten Mile River, Harrington River, Warren River, Kickemuit River, and Pawtuxet River. In the south bay the most significant streams are Hunt-Potowomut River, Annaquahatchet River and Narrow River. About three-fourths of the land area of the State, almost 800 square miles, is tributary to Narragansett Bay. Many of the streams of the State have their headwaters in the northwest uplands, where they occupy narrow, steep sloping valleys. In the lowlands, these streams generally are sluggish and meandering; and in the vicinity of the bay or ocean, they form fairly wide tidal estuaries.

Most of the coastal rivers are tidal to some extent bringing salt water in the lower parts of the stream channel well up into the land interior. Even though a groundwater location may be miles away from the bay coastline, if it is on a tidal river, salt water intrusion is a strong possibility. The position of salt water depends both on the depth of the channel and the freshwater outflow, hence generally moves up and
down the length of a natural stream seasonally.

Most streams in Rhode Island are considered effluent streams, that is streams which are lower than the surrounding water table and collect groundwater outflow. In late summer when precipitation runoff is greatly reduced the primary flow of these streams is contributed by groundwater. The quality of the water during low flow periods is directly indicative of ground water quality.

Lowering of the water table, such as by pumping, in proximity to a stream may reverse the gradient and induce infiltration of stream water into the ground. These can have consequences of groundwater contamination if the stream water is of poor quality as well as reduced stream flow. Thus in conducting subsurface operations near a stream it should be assumed that stream and groundwater are hydraulically connected.

GROUNDWATER

In consideration of the effects mining may have in the Narragansett Basin, the groundwater implications are potentially of greatest significance because of the large number of wells in the basin.

The following is taken from Lang (1961):

"The water-bearing formations that comprise the underground reservoirs of an area are called "aquifers." They differ greatly in thickness and extent. Two important factors, among others, govern the amount and availability of water in an aquifer. One is the porosity of the aquifer, that is the ratio of pore space to the total volume of the aquifer, expressed as a percentage. The porosity determines how much water the formation can hold. The other factor is the permeability of the aquifer, which determines how freely water can move through
it. Permeability and porosity thus are not synonymous. For example, clays that make up a large part of the till aquifers in Rhode Island are highly porous and can hold a great deal of water, but the pore spaces in the clay are so small that the water in them is locked into place by molecular forces. Hence wells drilled into clayey deposits may yield water at relatively low rates. The ratio of the volume of water that saturated material will yield to the total volume is known as the specific yield and is stated as a percentage. The beds of sand and gravel in the outwash are the most permeable aquifers of the state.

The openings in the unconsolidated rocks are known as "original or primary openings," because they were formed as the grains of material that compose their walls were deposited. "Secondary openings," on the other hand, are those which were formed after the rocks were deposited, by stresses that accumulated until the rocks were ruptured. Open joints or fractures in consolidated rocks are examples of this type. Joints and fractures commonly occur in sets, in which the individual joints are more or less parallel. In many places two or more sets of joints intersect each other. They are generally most numerous near the surface, becoming fewer in number and narrower in width with increasing depth. Where joints are numerous and open they not only allow relatively free movement of groundwater, but also permit the storage of moderate quantities of water.
Openings may occur also along bedding planes in sedimentary rocks. In the rocks of Carboniferous Age of the Narragansett Basin the water tends to be concentrated in and transmitted along the bedding planes. Bedding planes probably do not exist as actual cavities visible to the eye, but rather as narrow openings along planes of parting. Wells that intersect bedding planes draw part of their water at such horizons."

The specific characteristics of aquifers in the Narragansett basin are summarized in Table 1. It is to be noted that well yields may vary from as little as 1 gallon per minute (gpm) in rock to 1300 gpm in glacial outwash. Glacial outwash, because of its productivity, is by far the most important water bearing material in the Narragansett Basin. Plate 1 shows the areal distribution of glacial outwash in the Narragansett basin and the location of major wells. Also shown on Plate 1 is the theoretical radius of influence for the well assuming a table aquifer receiving a recharge of 10 inches/year. It is emphasized that this is theoretical and intended only to give an indication of the relative magnitude of effect from pumping at maximum yields to show actual limits of influence.

Groundwater occurs in the Narragansett Basin in three general categories of geologic material: glacial outwash, glacial till and bedrock. The approximate distribution of till and outwash is shown in Figure 4. The bedrock in the Narragansett basin is sedimentary rock. The hydrologic characteristics of each of these geologic materials is described in detail in Appendix A.
<table>
<thead>
<tr>
<th>LOCATION (QUAD)</th>
<th>TYPE OF MATERIAL</th>
<th>HYDRAULIC CONDUCTIVITY (FT/DAY)</th>
<th>AQUIFER THICKNESS (FT)</th>
<th>TRANSMISSIBILITY (AVERAGE) (FT²/DAY)</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>O</td>
<td>780 ft./day</td>
<td>60 (ave.)</td>
<td>46,500</td>
<td>Bierschenk, 1954</td>
</tr>
<tr>
<td>E. Greenwich</td>
<td>O</td>
<td>130-530 ft./day</td>
<td>0-215</td>
<td>35,790</td>
<td>Allen, 1956</td>
</tr>
<tr>
<td>E. Providence</td>
<td>O/T/R</td>
<td>300-1300 gpm</td>
<td>0-130</td>
<td>2-3 gpm</td>
<td>Allen &amp; Gorman, 1959</td>
</tr>
<tr>
<td>Fall River</td>
<td>O/R</td>
<td>100-35 gpm</td>
<td>0-370</td>
<td>2-3 gpm</td>
<td>Allen &amp; Ryan, 1960</td>
</tr>
<tr>
<td>Narragansett</td>
<td>O/R</td>
<td>20-300 gpm</td>
<td>0-190</td>
<td>2-3 gpm</td>
<td>Hahn, 1959</td>
</tr>
<tr>
<td>Pler</td>
<td>T/O/R</td>
<td>25-400 gpm</td>
<td>0-98</td>
<td>7 gpm (ave.)</td>
<td>Schner &amp; Gonthier, 1956</td>
</tr>
<tr>
<td>Newport</td>
<td>T/R</td>
<td>12 gpm</td>
<td>0-75</td>
<td>1-55 gpm</td>
<td>Schner &amp; Gonthier, 1956</td>
</tr>
<tr>
<td>Providence</td>
<td>O</td>
<td>214-441 ft./day</td>
<td>29-90</td>
<td>14-1300</td>
<td>Bierschenk, 1959</td>
</tr>
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<td>Providence Is.</td>
<td>O</td>
<td>129 gpm</td>
<td>0-25</td>
<td>12-75 gpm</td>
<td>Schner &amp; Gonthier, 1956</td>
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<tr>
<td>Tiverton</td>
<td>R</td>
<td>30-800 gpm</td>
<td>0-135</td>
<td>0-41</td>
<td>Johnson &amp; Marks, 1959</td>
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<td>Wickford</td>
<td>O/T/R</td>
<td>468 ft./day</td>
<td>20-120</td>
<td>6-10 gpm</td>
<td>Rosanshein, 1956</td>
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<td>SAG</td>
<td>200 ft./day</td>
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<td></td>
<td></td>
<td>Gonthier &amp; Allen, 1968</td>
</tr>
<tr>
<td>S</td>
<td>107 ft./day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>54 ft./day</td>
<td></td>
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</table>

**Key to Type Material**

- O - outwash
- T - till
- R - rock
- G - gravel
- S - sand
- FS - fine sand

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FIGURE 4. Approximate areal distribution of till and outwash deposits in Rhode Island (from Allen, 1953)
WATER SUPPLY IN THE NARRAGANSETT BASIN

WATER SYSTEM COVERAGE

There are twenty one Rhode Island cities and towns lying wholly or in part in the Narragansett basin. The total population in the Narragansett basin is estimated at 494,000, based on 1980 U.S. Census figures. Most of the developed area in the Basin has public water service. However, there are notable exceptions, such as Jamestown, where one fourth of the population (1000 persons) is dependent on private wells. The areas served by public water systems based on the status as of 1980 are identified on Plate 2. A summary of the Narragansett Basin water supply systems is provided in Table 2.

SOURCES

The source of water for public water supply systems falls in three categories: water from surface reservoirs, groundwater from wells, or transfer water from other systems. A very large amount of transfer water used in the basin, probably about 60% of the total, comes from the Scituate Reservoir Complex, located approximately 6 miles to the west of the Basin. The remainder of the water comes from small reservoirs in or near the areas served, or from large capacity wells. The location of these sources is shown in detail on Plate 3. Table 3 provides a detailed listing of Narragansett Basin surface public water supply locations, and Table 4 is a detailed listing of public water supply wells. The information has been gleaned from a wide variety of references as noted, and verified to the extent possible by direct query to the water system managers.

While coverage of the Narragansett Basin by public water supply systems is fairly complete, it should be recognized that many private and
<table>
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<tr>
<th>SYSTEM NAME</th>
<th>WRB No.</th>
<th>LOCATION SERVED QUADRANGLE</th>
<th>SUPPLY TYPE</th>
<th>SOURCE LOCATION</th>
<th>PERSONS SERVED</th>
<th>QUANTITY (1980-1986)</th>
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<tr>
<td>Bristol Cnty Water Co.</td>
<td>2</td>
<td>Bristol</td>
<td>SW</td>
<td>Warren</td>
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<td></td>
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<td>Fall River</td>
<td>GM</td>
<td>Barrington</td>
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<td>Franklin</td>
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<td>Warren</td>
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<td></td>
<td></td>
<td>Pawtucket</td>
<td>GM</td>
<td>Barrington</td>
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<td>E. Providence Water Division</td>
<td>4</td>
<td>E. Providence</td>
<td>TW</td>
<td>Providence</td>
<td>50,980</td>
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<td>Jamestown Water Co.</td>
<td>8</td>
<td>Wickford Prudence Is</td>
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<td>Narrag. Pier Newport</td>
<td>3,500</td>
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<td>9</td>
<td>E. Greenwich</td>
<td>GM</td>
<td>E. Green. W. Warwick Providence</td>
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<td></td>
<td></td>
<td>GM</td>
<td></td>
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<td>11</td>
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<td>GM</td>
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<td>15,000</td>
<td>2.62</td>
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<td></td>
<td></td>
<td>GM</td>
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<td></td>
<td></td>
<td>TW</td>
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<td></td>
<td></td>
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<td>N. Tiverton Dist. Water</td>
<td>15</td>
<td>Fall River</td>
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<td>Fall River</td>
<td>2,200</td>
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<td>17</td>
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<td>SW</td>
<td>Pawtucket Pawtucket</td>
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<td>13.30</td>
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<td>TW</td>
<td>Newport Tiverton</td>
<td>12,100</td>
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<td>Providence</td>
<td>SW</td>
<td>Scituate</td>
<td>450,000</td>
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<td>SOURCE LOCATION</td>
<td>PERSONS SERVED¹</td>
<td>QUANTITY (1980-MGD)¹</td>
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<td></td>
<td>Prudence Is</td>
<td>GM</td>
<td>Prudence Is</td>
<td></td>
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</tr>
<tr>
<td>S. Kingstown Bd of Water Commissioners</td>
<td>21</td>
<td>Narr. Pier</td>
<td>GM</td>
<td>So. Kingst.</td>
<td>3,000</td>
<td>0.24</td>
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<td>Stonebridge Dist. Water</td>
<td>22</td>
<td>Tiverton</td>
<td>SM</td>
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<td>24</td>
<td>E. Greenwich</td>
<td>TW</td>
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<td>78,500</td>
<td>7.24</td>
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Notes: 1. Figures are for total system, including Narragansett Basin Use

2. SM - surface water; GM - ground water; TW - transfer water from another water system
<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>RESERVOIR NAME</th>
<th>QUADRANGLE</th>
<th>LOCATION</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>AVERAGE DEPTH (FT)</th>
<th>SURFACE AREA (ACRES)</th>
<th>BASIN AREA (SQ. MI)</th>
<th>STORAGE CAPACITY (MG)</th>
<th>REFERENCE</th>
<th>NOTES</th>
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<td>Arcow (Mass)</td>
<td>Somerset</td>
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<td>116</td>
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<td>(A Reservoirs)</td>
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<td>In Palmer and</td>
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<td>50</td>
<td>4.9</td>
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**NOTES:**

- A. outside Narragansett Basin

**REFERENCES:**

1. GB 6, Groundwater Resources of RI, Allen, 1953
2. 200 Study, Water Quality Management Plan, SWR, 1999
3. Task Eight, RI Lakes and Ponds, WRI, 1974
5. GHG, Groundwater Resources of Bristol Quad, Blazesheft, 1954
6. User information
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<tr>
<th>SYSTEM</th>
<th>WELL NUMBER</th>
<th>LOCATION</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>AQUIFER MATERIAL</th>
<th>DEPTH (FT)</th>
<th>CAPACITY (GPM)</th>
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<td>BAR 111</td>
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<td>83' to BR</td>
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<td>BAR 178</td>
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<td>71'</td>
<td>425</td>
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<td>WAK 33</td>
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<td>79'</td>
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<td>Lincoln</td>
<td>LIN 335</td>
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<td>71°24'42&quot;</td>
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<td>107'(110' to BK)</td>
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<td>136' to BR</td>
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<td>LIN 383</td>
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<td>71°25'28&quot;</td>
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<td>62'</td>
<td>650 (NIU)</td>
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<td>LIN 417</td>
<td>(3) 41°58'05&quot;</td>
<td>71°27'58&quot;</td>
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<td>55'</td>
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<td>LIN 418</td>
<td>(4) 41°54'08&quot;</td>
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<td>14'</td>
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<td>5,6</td>
<td>54'</td>
<td>726</td>
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<td></td>
<td>LIN 420</td>
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<td>46'</td>
<td>1000 (NIU)</td>
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<td>(10) 41958'</td>
<td>71°27'</td>
<td>5,6</td>
<td>95'</td>
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<td>(11) 41954'</td>
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<td>NOK 26</td>
<td>41°33'30&quot;</td>
<td>71°28'40&quot;</td>
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<td>50'</td>
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<td>41°33'10&quot;</td>
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### TABLE 4  NARRAGANSETT BASIN PUBLIC WATER SUPPLY WELLS  (Continued)

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<th>WELL NUMBER</th>
<th>LOCATION</th>
<th>AQUIFIER MATERIAL</th>
<th>DEPTH (FT)</th>
<th>CAPACITY (GPM)</th>
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<td>North Tiverton</td>
<td>TIV 1</td>
<td>41°38'00''N</td>
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<td>12.6</td>
<td>NIU</td>
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<td>Fire District</td>
<td>TIV 47</td>
<td>71°01'30''W</td>
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<td>27' to BR</td>
<td>NIU</td>
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<td>(3 wells)</td>
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<td>41°40'00''N</td>
<td>S 6</td>
<td>16' to BR</td>
<td>20 NIU</td>
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<td>Pawtucket</td>
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<td>(10 wells)</td>
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<td>703</td>
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<td>POR 235</td>
<td>41°36'10''N</td>
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<td>221' (13' to BK)</td>
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<td>300' (16' to BK)</td>
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<td>7(6 wells)</td>
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<td>4'</td>
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<td>POR 240</td>
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<td>24'</td>
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<td>280' (23' to BK)</td>
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**NOTES:**

A. Code S - Sand
   G - Gravel
   U - Unconsolidated Sediment
   R - Rock
   NIU - Not in use
   ( ) - Level well number

B. Reference Key

1. (Bierschank, 1954)
2. (Allen, 1953)
3. (Allen, 1956)
4. (Johnson and Dickerman, 1974)
5. (Gontier, 1966)
6. (Johnson and Hanks, 1959)
7. USGS Files, Providence, R.I. Office
8. Water Agency Information
small industrial wells exist even in covered areas. These wells are frequently used for supplement supply. Therefore, any alternate use, or effect on, groundwater by mining activity must also take these wells into consideration.

**CITY AND TOWN WATER SUPPLY PROFILES**


1. **Town of Barrington** (population 16,181)
   Water supply is provided by the Bristol County Water Company from three wells located in the town.

2. **Town of Bristol** (population 20,165)
   The northwest half of the town lies in the Basin. The Bristol County Water Company provides public water to most of the areas where concentrated development exists in the community. Sources are both groundwater and surface water.

3. **City of Central Falls** (population 16,901)
   The entire City is served by a public water system supplied by the City of Pawtucket water system. Sources are groundwater and surface water.

4. **City of Cranston** (population 71,936)
   The east half of the City lies within the basin. With the exception of western Cranston, which has no water distribution system, water supply in this community is provided by the Kent County Water Authority and the City of Providence water system.
5. Town of Cumberland (population 27,009)

Only the eastern one third of the town lies within the Narragansett basin. The town is served both by the Town of Cumberland Water Supply department and by the City of Pawtucket Water Department.

6. Town of East Greenwich (population 10,208)

Only a small part of town in the northeast corner is within the Basin. Water supply is provided in the developed areas of the town east of South County Trail (Route A. 1. 2) by the Kent County Water Authority.

7. City of East Providence (population 50,960)

The City is served by a municipal water system which is supplied by the City of Providence.

8. Town of Jamestown (population 4,028)

The public water system in this community serves only the central part of the town. The water supply sources are Carr Pond and Watson Pond.

9. Town of Little Compton (population 3,086)

Only a small part of town in the northwest corner is in the basin. The town has no public water distribution system. The population is served by private wells.

10. Town of Middletown (population 17,251)

The water distribution system in Middletown is supplied by the City of Newport water system from surface water sources.

11. Town of Narragansett (population 14,097)

Only the north one third of the town is in the basin. The town has two water distribution systems. The Point Judith system which serves the southern portion of the town is supplied by the Wakefield Water Company. The North End system which serves the northwest portion of the town is supplied by the Town of North Kingstown Water Department. Gravel packed
wells are the sources of supply for both of these systems.

12. City of Newport (population 29,266)
   About two thirds of the city is in the basin. The Newport water system has reservoirs in Tiverton and Little Compton and several small ones on Aquidneck Island. Most of the City is served by the public water distribution system.

13. Town of North Kingstown (population 21,855)
   The North Kingstown Water Department, which provides water to most of the town, has wells as the source of supply.

14. Town of North Providence (population 29,216)
   The town is supplied both by the Providence Water Supply Board System and by the City of Pawtucket Water Department.

15. City of Pawtucket (population 71,035)
   The entire city is served by a public water supply system which obtains most of its water supply from surface water and a small amount from wells. The surface water supply is the Abbott Run watershed in Cumberland which, after impoundment in Diamond Hill and Arnold Mills Reservoirs, flows to Happy Hollow Pond through Abbott Run. The groundwater supplement is from wells located in Pawtucket and Cumberland.

16. Town of Portsmouth (population 14,256)
   There are two water distribution systems which are owned and maintained by the Portsmouth Water and Fire District. The area north of Sprague Street to Common Fence Point is supplied by the Stone Bridge system in Tiverton, while the area south of Sprague Street to the town line obtains its supply from the Newport system.
17. **City of Providence** (population 156,519)  
The entire city is served by a public water supply system. The source of supply is the Scituate Reservoir complex in the Town of Scituate.

18. **Town of South Kingstown** (population 20,411)  
There are three water systems which serve this community. The Wakefield Water Company serves the Wakefield-Peace Dale area. The Kingston Fire District serves the Village of Kingston, and the South Kingstown Water Company serves the area south of Post Road (U.S. Route 1). Water supply for the three systems is from wells.

19. **Town of Tiverton** (population 15,484)  
Only the western shoreline is within the basin. There are two water systems which serve the Town of Tiverton: the North Tiverton Fire District which purchases its water from the City of Fall River, and the Stone Bridge Fire District which obtains its supply from Stafford Pond. The northwest portion of the town is the only area which is presently served by the two systems.

20. **Town of Warren** (population 10,620)  
The Bristol County Water Company provides water to this community. Several of the reservoirs which supply the system are located in adjacent Bristol County, Massachusetts.

21. **City of Warwick** (population 87,064)  
The City's water system is the largest in the state that does not have its own sources of supply. It serves most of the built-up areas of the city and obtains its water from the Providence Water Supply System. The Greenwood and Potowomut areas are served by the Kent County Water Authority.
MINE DRAINAGE EFFECT ON WATER LEVEL

SURFACE WATER

Pumping from mining excavations must be disposed of either into a detention basin or surface stream; in either case the normal progress of the hydrologic cycle is disrupted and at least a temporary abnormal incidence of surface water may occur. Under other hydrogeologic situations, namely where the water table is near the surface, wetlands, streams and ponds may disappear as a result of mine dewatering. Low permeability barriers such as clay-filled trenches or grouted bedrock can be considered in some cases to reduce infiltration into mine excavations. The possibilities of effect must be determined based on 1) geohydrologic nature of the subsurface material, 2) proximity of water table to ground surface, and 3) mine dewatering plan in discharge quantity and location.

A most important consideration related to surface water change is quality. Changes in quality of the original water body may be caused by the addition of poor quality mine drainage water or by the reduction of natural flow which can reduce the ability to dilute contaminant input into the stream or pond. An impact analysis of this effect must be site specific, involving the acquisition of baseline data of existing flow and water quality for at least one full year before mining operations occur. The nature of impaired water quality from mine drainage will be discussed later in this report.

Additional effects may be caused by modifications to the surface of the mining region; the ability of the ground surface to hold or transmit water may be greatly changed. Removal of vegetation cover generally will results in a less permeable ground surface with greater ponding and
runoff. Also, inversion of topography may cause ponding and reduced surface runoff. Review of detailed plans for the proposed mining area modification can allow assessment of this possibility.

Additionally, surface mining and subsequent area restoration may greatly alter the hydrologic character of material in the vadose zone immediately below the surface. As a result, the infiltration of precipitation downward may either be increased or decreased with consequences on both surface and groundwater levels. W.K. Summers (1981) offers a means of quantifying the impact of mining on groundwater recharge. The following is taken from the abstract of a presentation made at the Symposium on Surface Mining Hydrology at Lexington, Kentucky in 1981.

"...To measure the impact of surface mining on ground-water recharge, hydrogeologists must quantify both the pre-mining and post-mining recharge rates.

To quantify recharge rates at specific sites requires (1) the installation of suites of piezometers and tensiometers to determine the magnitude and direction of the hydraulic gradient and (2) in-situ measurements of soil-moisture content and hydraulic conductivity.

Because rates vary seasonally, measurements for a period of time (at least one year) before mining are necessary to determine the range and variation in the rate. If the flow through the partially saturated zone from the land surface to the water table follows fractures, recharge may occur at much faster rates than would be predicted for flow through the interstitial spaces of clastic rocks and soils. So, sufficient measurements to determine the mode of flow must be made.
In pristine areas, natural recharge may be the only consideration and measurements to determine the area and extent of the natural recharge phenomena may be sufficient. But, if the area has many water wells that are pumping to their capacity, regional gradients may be reversed and, locally, recharge may be induced in discharge areas. So, the rates observed may be changing for reasons other than mining and these changes must be quantified before mining if the effects of mining alone are to be characterized.

GROUND WATER

Pits, drifts and headings created as a part of the mining operation frequently incise into water bearing strata. This is particularly true in the Narragansett basin where the land surface elevations are low and relatively near the bay. The encounter with groundwater may be under water table or artesian conditions. Extraction of water from the mining excavation will result in a depression of the water table or piezometric surface. This lowering of the water table may create problems for wells both in unconsolidated sediments as well as in rock. Frequently the fractured and faulted coal beds become conduits for groundwater movement and storage. Wells in coal seams may have higher yield than in the roof or floor rock of mines.

The following information is taken primarily from the excellent discussion on potential coal mining impacts by Frimpter and Naevsky (1979).

"Dewatering of bedrock for mining requires only the removal of water from storage in secondary porosity (joints and fractures) in the bedrock and removal of water from storage in
primary porosity in overlying unconsolidated deposits hydraulically connected with the bedrock. The specific yield of a rock is the ratio of volume of water that will drain by gravity from water-saturated rock to the volume of the rock. Because primary pores of the conglomerate and sandstone of the Rhode Island Formation in the Narragansett basin are very poorly interconnected and because secondary pores (joints and fractures) make up only a small percentage of total rock volume, specific yield of the upper 300 feet of bedrock is estimated to be less than 0.5 percent. The degree of rock fracture and therefore specific yield is greatest near the top of the bedrock and decreases rapidly to a negligible amount between 300 and 400 feet.

Unconsolidated sand and gravel deposits of glacial origin in New England commonly have specific yields of about 20 percent and therefore may store large quantities of water. For example, a 1-mile-long section of a 1-mile-wide valley filled to an average depth of 30 feet with water-saturated sand and gravel constitutes a ground-water reservoir that contains 1.1 billion gallons of water. The aquifer mapped by Williams (1968) between Lake Mirimichi and Greenwood (dungay) Lake in Mansfield and Foxborough is about this size but is also in contact with the lakes and additional water-saturated sand and gravel both to the north and to the south. Mansfield withdraws an average of 1 Mgal/day from wells in this ground-water reservoir, and Attleboro has a pumping capacity of 2.75 Mgal/day at its diversion station on the Wading River in Mansfield (Williams and Willey, 1967). Base flow in the Wading River at this station is
partly dependent on ground-water discharge from the 1.1 billion
gallon ground-water reservoir and releases from Lake Mirimichi.
Mines close to the ground-water reservoirs such as this would
have a large potential for ground-water inflow. However, there
commonly is a layer of till separating rock from sand and
gravel, so inflow to rock would depend on the thickness and
permeability of the till and the hydraulic gradient induced by
dewatering.

Sustained high rates of ground-water seepage to mines are
not expected unless the mines are in proximity to large bodies
of surface water or water-saturated glaciofluvial deposits.
Avoidance of infiltration from water-saturated glaciofluvial
deposits to minimize mine seepage and pumping costs would also
lessen chances of interference with public-supply wells tapping
glaciofluvial deposits. However, interference with domestic
water-supply wells tapping bedrock should be expected near
underground or deep-pit operations. Historical and hydrologic
evidence indicate that mining operations could cause local
dewatering of the bedrock aquifer and resultant failure of
domestic water-supply wells. Public water-supply service might
be extended into areas where mining might have this effect."

The following historic note of relevant interest is also contained in
the Friepeter and Moevsky (1979) report.

"Water problems were encountered in the early prospecting
and mining efforts in the last century in the Mansfield,
Massachusetts, area. During dewatering of the 84-foot Skinner
mine shaft west of Tremont Street in Mansfield, home wells went
dry. On August 24, 1923, the Mansfield News reported: "The first attempt to pump out the water was successful although continuous pumping is necessary to keep the shaft dry." On August 31, the News reported: "Following a lengthy hearing at the Selectmen's meeting last night, given to several residents of Tremont St., West Mansfield, whose supply of water has dwindled to nothing on account of the continuous pumping at the coal mine, the Board voted to call a town meeting on September 17 to take action on the matter..." And, on September 31, "A debate of an hour at the special town meeting Monday evening resulted in the Selectmen and town manager being empowered to furnish relief for any resident who has no supply of water. Albert H. Bagloe said that the wells were only dry when the mine was being pumped."

"Harry B. Chase (oral commun., 1976) reported that an early attempt to develop the Haroon mine north of School Street in Mansfield ended in 1838 because of water, difficulty of mining steeply inclined seams, and national depression. Mr. Chase also reported that in 1917-18 mining operations at the Haroon mine failed because of inability to pump out the shaft; that in 1920 two to five pumps ran continuously to drain the mine; and that in 1922-23 a 25-horsepower electric pump failed to pump the shaft dry."

Once the mining plan and site condition are known, predictions of probable inflow into mining excavations and lowering of the water table can be made. McWhorter (1981) presents practical closed form formulas by which inflows and drawdowns can be calculated for several selected situations. Cases covered are 1) flow to an advancing pit, 2) effect of
pit elongation, 3) effect of leakage on extent of affected piezometric surface and 4) drainage of alluvium or fault zone by adjacent pit.

A good engineering treatment of the ground water and geotechnical problems involved in tunneling and open excavations is given by Freeze and Cherry (1979). Concepts are discussed and predictive equations given.
SALT WATER INVASION

CONCEPT

Coastal land masses in proximity to salt water such as Narragansett Bay commonly develop a groundwater feature of particular importance in mining operations. Fresh groundwater flowing to discharge at the shoreline of the bay overrides deeper salty groundwater and must maintain a hydrostatic balance with the underlyng salty groundwater. The fresh water of lesser density than salt water tends to float on the salt water. The thickness of the fresh groundwater body becomes less as the shoreline is approached, finally tapering to no thickness as it exits into the salt water of the open bay. This relationship is commonly termed the Ghyben-Herzberg relation (Foidl, 1959). When usual values of 1.00 and 1.025 are taken for fresh water and sea water density respectively are assumed it is found that on a theoretical basis for every foot the fresh water stands above mean sea level there are approximately forty feet of fresh water to the underlyng salt water interface. A very complete discussion of this phenomenon is provided by Bear (1979).

In practice there are important differences between theory and reality. First, the interface is not sharp, but a transition zone which may greater reduce the fresh water thickness. Secondly the water levels and the position of the interface are highly dynamic, fluctuating daily with the tide and seasonally with the amount of fresh water recharge into the ground. Finally the actually position and integrity of the fresh water body is dependent on the amount and nature of voids in the subsurface material; this is particularly important in rock where large fissures in direct communication with the sea can allow salt water to intrude much more rapidly than in unconsolidated sands where subsurface
flow must take a slower more tortuous path. In contrast however, tight bedrock may form an impervious boundary protecting against salt water intrusion into a aquifer. The relationship between fresh water and the underlying salt water during pumping is illustrated in Figure 5. As indicated, deeper wells are the first to show the effects of salt water intrusion. Any well, however, can be affected when the fresh water level at that well is lowered below mean sea level. This is important since mine dewatering would be continued regardless of whether the water pumped was fresh or salt. This then could adversely affect supply wells in the area by reducing the fresh water thickness to less than the depth of the well.

CURRENT PROBLEMS

According to Frippeter (1973) salt water encroachment from Narragansett Bay and associated lagoons, coves and estuaries is a threat to groundwater quality under normal conditions. Under conditions of extensive dewatering from mining excavation the potential for salt water encroachment is much greater, particularly due to the likelihood of reversing normal groundwater gradients. Frippeter (1973) notes that public supply wells in Barrington, less than half a mile from Narragansett Bay, yielded water with a chloride content of 15 mg/l (milligrams per liter) in 1952. Since then, chloride content has increased. One of the wells has yielded water with a chloride concentration of 460 mg/l in 1966. The danger of salt-water encroachment was recognized (Allen, 1953) long before the increase in chloride content. Pumping of wells in the aquifer reverses the natural hydrologic gradient between the wells and Narragansett Bay, causing landward
Figure 5  Relationship between salt water and fresh water in a coastal aquifer during pumping (from Mazzaferro et al, 1979)
encroachment of a salt-water wedge in the lower part of the aquifer. At the well, salt water is withdrawn with fresh water. Unless pumping rates are carefully controlled, the chloride content will continue to increase, particularly during dry summers. Chloride concentration in these and similarly situated wells can be expected to fluctuate seasonally. Because the salt/fresh-water interface migrates during periods of fresh-water recharge (in the spring), less salt water will mix with the fresh water in the well; and during periods of no recharge (in the summer), more salt water will mix with it. During short-term recharge periods, chloride content diminishes, but salt-water encroachment is increasing on an annual basis.

The Barrington region is worthy of further examination since early monitoring (Siershank, 1954) did not show a salt water intrusion problem though it was recognized that the water table gradient reversal could induce salt water encroachment. Figure 6 is a map of the Barrington area showing the elevations of static water levels in wells during the period July-September 1949. Also identified on Figure 6 are the traces of two cross sections A-A' and B-B' which are shown in detail in Figures 7 and 8 respectively. From Figure 6 it is apparent that the water table in Barrington reached a maximum of only 10 feet above sea level. Drawdown in wells would in most cases exceed this thus reducing the head available to counter salt water intrusion to less than sea level.

Wells or excavations that tap outwash deposits near tidal waters or that pump large quantities of water for a prolonged period of time may induce salt-water encroachment if the water table is drawn below sea level resulting in a hydraulic gradient favorable to such intrusion. The only known area in Barrington where such a gradient occurred according
FIGURE 6  Map of Barrington, Rhode Island showing altitude of static water levels in water table wells as of July-September 1949 and locations of hydrogeologic cross sections (after Bierschenk, 1954)
FIGURE 7 Hydrogeologic cross section A - A' at Barrington, Rhode Island
(from Bierschenk, 1954)
FIGURE 8: Hydrogeologic cross section B-B' at Barrington, Rhode Island (From Bierschenk, 1964)
to Biershank (1954) was at the well field of the Bristol County Water Co. However, data at that time did not show any sea-water contamination of the outwash deposit from which water is pumped. In both wells Bar. 111 and 119, which are about 2,000 feet from Narragansett Bay, the concentration of chloride was 12 parts per million (ppm) in 1950. It was 15 ppm in June 1952 when the wells were first put into operation, and it was 10 to 15 ppm, respectively. In 1966, however the concentration was 460 mg/l in October 1953. In well Bar. 10, about 600 feet from the bay, the chloride concentration was 20 ppm in December 1953. The fresh-water head in observation well Bar. 10, between the supply wells and the bay, ranged from a maximum of about 7 feet to a minimum of something less than 2 feet above sea level. During the period of the Biershank (1954) study there appeared to be a fluctuating positive head of water with a hydraulic gradient from well Bar. 10 toward the sea that prevents landward migration of sea water. It is also possible that a body of impermeable lacustrine clay lies underneath the Nayatt kame delta and extends beneath Narragansett Bay. If so, it may have acted at least as a temporary barrier to landward movement of sea water. It is evident that sea water intrusion is a long term event responding to changes in the hydrologic system slowly, in a time frame which may be measured in years.

The outwash deposits in Warren underlie an irregularly shaped area in the northeastern part of the quadrangle. They range in thickness from a few inches at the rick outcrops east of the Warren Reservoir to a reported maximum of 90 feet at well Wan. 66 southeast of the outcrops. In addition to the fine grained character of most of the outwash in Warren, three other features are significant. The first is that nearly everywhere the saturated portion is not over 30 feet thick. Except where the outwash rests against the higher hills, the bedrock surface ranges
from a few feet above to about 30 feet below sea level. Accordingly, there is no deep-lying body of saturated materials to draw upon, as there is in Barrington. Second, the outwash bodies are narrow and, generally not more than about half a mile from salty, tidal water. Third, there is no known evidence of any strata or zones impermeable enough either to confine water under artesian pressure or to prevent the downward or lateral movement of water from the land surface, or from the bay. Because of the generally fine-grained nature of the deposits, their thinness, and probable continuity with salty bay water, the outwash deposits of Warren are vulnerable to salt water intrusion.

The outwash deposits in the towns of Bristol, Portsmouth, and Warwick are in small thin bodies of irregular areal extent, generally bordering the till-mantled bedrock hills. They probably consist of stratified gravel, sand, and silt, and perhaps clay. On the west side of the principal land area of Bristol, the outwash deposits are 10 feet thick or less and on the east side, at wells 101 and 134, they are 20 and 30 feet thick, respectively, and consist of gravel, sand, and silt. Data are not available on the thickness of the outwash on Patience and Prudence Islands in Portsmouth (southwestern portion of the quadrangle), but the deposits are probably not more than 30 feet thick. The groundwater in these areas is presumed to be generally unconfined. The water table is at altitudes of 1 to 40 feet above sea level, and at most places not more than 10 feet below land surface. The deposits are thin and are all in close proximity to Narragansett Bay, hence de-watering in mine excavations would probably draw in sea water.

The following is taken from Biershank (1954):

"Many rock wells situated near Narragansett Bay can encounter or draw in sea water through the fractures. On
Popasquash Neck, in Bristol well Bri. 10 intersected a fresh-water-bearing fracture at a depth of 70 feet. However, at a depth of 140 feet it encountered a salt-water "vein." Thus the water supply was contaminated. On the same property, well Bri. 11 encountered at a depth of 60 feet fresh water which rose to about sea level. The well yielded 7 gpm of fresh water. Just east of Bristol Harbor, well Bri. 25, drilled to a depth of 203 feet, yields brackish water. This well, which reportedly had a static water level approximately at sea level when drilled in 1933 and which originally yielded fresh water, is pumped for 24 hours per day at a rate of about 40 gpm and thus, more than likely, has drawn in the sea water. On the east shore of Warren River, abandoned wells Wan. 35, 74, and 76, ranging in depth from 500 to 530 feet, yielded brackish water when drilled. However, nearby wells Wan. 31, 32, 33, and 38, ranging in depth from 50 to 104 feet supply fresh water.

TEST RESULTS

The potential salt water intrusion effect of mining operations on groundwater in the Narragansett basin was evaluated by Freymeter and Maevsky (1979), using test hole observations. The U.S. Geological Survey measured water levels monthly in 13 cased holes penetrating the Rhode Island Formation in Rhode Island and Massachusetts. In addition continuous records of water level fluctuations was obtained on six test holes for periods ranging from about a week to 2 months. Complete well logs are available for these test holes. Water level fluctuations and salinity determinations enabled estimates to be made of the salt water intrusion potential at the test sites. Well records and location sketches are contained in Appendix B.
A measure of the relationship of groundwater to tidal influenced water bodies can be obtained by observing the water level response in a well to tidal fluctuation. This should be done in any area where it is proposed to undertake pumping and dewatering. This was accomplished for two of the Rhode Island test holes, Bristol 23 and 64.

Water-level recorders placed on Bristol 23 and 64 showed (Fig. 9) that water levels in these holes fluctuated diurnally in response to tides in Narragansett Bay, as did water levels in a mine pit in Bristol (Conrad Beauregard, Bristol resident, oral commun., 1977). Bristol 23 had a range of about 1 foot, whereas Bristol 64 had a range of 1.5 feet. Typical tidal characteristics for the region are shown in Figure 10.

Because the tidal range in Narragansett Bay at Bristol during this period was 5.4 feet, the tidal efficiency of these test holes is 18 and 28 percent, respectively. Fluid-conductance logs of these test holes indicate they contain saltwater. Pumping for 5 hours did not yield freshwater. These data and a specific capacity of 0.25 to 0.39 gallons per minute per foot of drawdown for test holes 7 and 23 strongly suggest that mine shafts, tunnels, or pits would encounter high inflow or seepage rates at this location.

Additional indications of the potential salt water intrusion problem were in evidence during test pumping of test hole Bristol 23. A graphic record of the pump test is shown in Figure 11. The following pertinent comments are taken from Frimpter and Maarvsky (1979).

"During the pumping of Bristol 23 (Fig. 11), water color gradually changed from black to gray. At about 180 minutes, it turned black again and yield increased as a result of the unplugging of a water-bearing fracture in coal or carbonaceous shale. Water from Bristol 7 and 23 remained salty throughout
Figure 9  Tidal water level fluctuations of groundwater in wells at Bristol, Rhode Island (from Frimpter and Maevsky, 1979)
TIDAL CHARACTERISTICS

Along the coast there are two high tides and two low tides each lunar day (24 hours and 50 minutes). The difference between high and low tide is greater than average at times of new or full moon and less than average at times of first or third quarter moons.

Figure 10 Tidal characteristics for Mount Hope Bay, Rhode Island (from Willey, 1978)
Figure 11: Drawdown from pumping test of test hole Bristol 23
(from Frimpter and Moevsky, 1979)
pumping and remained at 18°C - warmer than the 11°C–12°C common for shallow ground water in southeastern New England. The rapid and nearly complete recovery of water levels in Bristol 7 and 23 suggest little depletion of water in storage. The water level in Bristol 7 declined 0.8 foot during pumping of Bristol 23, owing to low tide in Narragansett Bay 220 feet to the west."

MINING IMPLICATIONS

The foregoing tests strongly suggest that the test holes, located generally in the area of potential coal mining operations, are in hydrologic contact with Narragansett Bay and that mining would facilitate saltwater seepage. Whether or not this is of any real significance requires site specific evaluation of the planned mining operation vis à vis use of groundwater in the area.

In the location and construction of mine facilities and excavations consideration must also be given to the possibility of surface flooding from salt water. Protective berms to prevent flooding from 1938 hurricane levels should be required. The bay water rose during this event by almost 14 feet above mean sea level. Tidal flooding potential is shown graphically in Figure 12.
TIDAL FLOODING

UNPROTECTED, LOW LYING COASTAL AREAS ARE SUBJECT TO TIDAL FLOODING FROM HURRICANE SURGES. - From 1625 to 1974 tidal levels along the coast have exceeded those of September 21, 1938, and August 31, 1954, only on August 21, 1926, and August 15, 1635 (U.S. Army Corps of Engineers, 1965, and Paulsen, 1940).

Figure 12 Tidal flooding at Mount Hope Bay, Rhode Island (from Willey, 1978)
Acid Mine Drainage

Acid mine drainage is an extremely acidic, iron sulfate rich drainage that forms under natural conditions when certain coal seams are exposed to air and water. When coal is mined, the iron disulfides, occurring either as marcasite or pyrite, which are commonly associated with the coal and overlying strata, are exposed to the atmosphere and oxidize in the presence of humidity and oxygen to form soluble hydrous iron sulfates. Subsequent contact dissolves these compounds which chemically react to produce a highly acidic drainage with attendant high concentrations of iron and sulfate. Although this process is generally accepted as the mechanism by which acid mine drainage is formed, the exact chemical reactions are not fully understood (Carruccio et al., 1977).

Chemical reactions explaining the oxidation of the iron disulfide and the generation of acidity are given by the following equations:

$$\text{FeS}_2(s) + 7/2 \text{O}_2 + \text{H}_2\text{O} = \text{Fe}^{++} + 2\text{SO}_4^{2-} + 2\text{H}^+$$  
(1)

$$\text{Fe}^{++} + 1/4\text{O}_2 + \text{H}^+ = \text{Fe}^{+++} + 1/2\text{H}_2\text{O}$$  
(2)

$$\text{Fe}^{+++} + 3\text{H}_2\text{O} = \text{Fe(OH)}_3(s) + 3\text{H}^+$$  
(3)

$$\text{Fe}_2\text{S}_2(s) + 14\text{Fe}^{+++} + 8\text{H}_2\text{O} = 15\text{Fe}^{++} + 2\text{SO}_4^{2-} + 16\text{H}^+$$  
(4)

(Singer and Stumm, 1968)

On the surface of a weathered coal mine face, yellow and white crusts commonly occur along certain horizons within the strata. These white and yellow salts are the oxidation products of the pyrite and are the crystallized products of equation 1. Some of the products have been identified as melanterite (white crystals of ferrous sulfate), copiapite (yellow crystals of ferric sulfate), halotrichite (white crystals of iron...
or magnesium sulfate), and aluminogenite (white crystals of aluminum sulfate) (Lorenz, 1962).

The ferrous iron generated in the reaction described in equation 1 can be further oxidized to the ferric state in accordance with equation 3 and generate additional amounts of sulfuric acid. It has been estimated by Stumm and Lee (1960) that a large part of the acidity generated in acid mine drainage production arises from the oxidation of ferrous iron to ferric iron. The ferrous and ferric hydroxides associated with the chemical reaction in equation 3 impart the red and yellow-orange color that is characteristic of acid mine drainage. The precipitated iron hydroxide is the "yellow boy" that is commonly observed in streams and coal mine areas.

The sulfuric acid causes the water to be highly corrosive. These chemical qualities make the water unsuitable for drinking and for almost any other use. They form a hostile environment for normal stream life, especially fish, and commonly cause the formation of an orange slime of iron hydroxides and iron-metabolizing bacteria (Trimmer and Maevsky, 1979). The following is taken from a study done by Caruccio et al. (1979) for the Environmental Protection Agency:

"Sulfur in coal can occur as organic sulfur, pyritic sulfur or sulfate sulfur. Organic sulfur is that component which is incorporated in the plant structure and is organically bound within the coal. In general, the organic component is not chemically reactive. Sulfate sulfur usually represents the water soluble weathering products of the disulfides and in most cases constitutes a very small percentage of the total sulfur measured in a section. Pyritic sulfur is that sulfur which is found in the disulfide phase usually as either marcasite or pyrite."
"Studies by Mansfield and Spackman (1965) have shown that variations in the total sulfur contents of coal samples collected from the bituminous coal field of western Pennsylvania reflect variations in pyritic sulfur contents. In their study the organic sulfur content of a particular coal seam remained relatively constant from the top to the bottom of the seam. Although the values of organic sulfur varied from 0.5 to 2%, variations in total sulfur content expressed variations in pyritic sulfur content within each seam."

"In comparing two areas in central Pennsylvania, Caruccio (1968) showed that the occurrence of acid mine drainage produced in the strip mine areas could not be related to the sulfur content of the coals and overlying strata. The two areas in Pennsylvania, one containing strip mines that produced acid, while the other containing mines with non-acid drainages, had strata with total sulfur contents which varied and overlapped and whose values were apparently similar. Microscopic examination of polished samples of coal and rock strata collected from the non-acid producing area showed them to contain abundant amounts of pyrite as well as total sulfur percentages that were similar to the samples from the acid producing area."

"In a combination of studies, selected samples of coal and rock were placed in leaching chambers and periodically flushed with distilled water. The quality of the leachate collected from each sample was analyzed and the degree of acidity produced by each sample ascertained. Representative splits of
the samples used in the leaching chambers were analyzed for sulfur contents and equal portions cast in polished pellets for microscopic examination. Caruccio (1968, 1969) found that the pyrite morphology was significantly different between the samples that produced acid and those that did not, even though the total sulfur contents were similar.

"In addition, there was a significant variation in the pyrite morphology between samples from the two areas of study. In samples from the non-acid producing area the pyrite commonly had a massive form and appeared to be secondary in origin. Most of the grains were greater than 400 microns and commonly had a morphology that suggested that the pyrite had replaced plant structures and occupied joints in the coal. In samples from the acid producing area, however, a major portion of the pyrite occurred as clusters of spheres measuring approximately 25 microns in diameter. Each of the spheres was an agglomeration of minute crystals of pyrite approximately 0.25 microns in diameter that collectively had globular morphology. Gray, Shapiro and Coe (1963) called attention to this type of pyrite occurring in the Pittsburgh seam of Pennsylvania, which is called framboidal pyrite."

"In terms of reactivity, Caruccio showed that framboidal pyrite is much more reactive and less stable than the massive secondary pyrite (1969, 1973). Samples containing framboidal pyrite when left in the lab were noted to readily decompose to produce the salt crusts that appear on the surface of the coals and which are products of the oxidation process. On the other hand, coarse grained particles of pyrite were noted to remain
shiny and brassy for indefinite periods of time and did not show appreciable signs of weathering. Subsequent studies by Caruccio (1970) showed that the percentage of frambooidal pyrite within samples of similar permeabilities, multiplied by the total pyrite content of that sample, can be used as a measure of the acid producing potential of that particular sample. In this manner, samples could have high amounts of pyritic sulfur, but if occurring as massive coarse grained secondary types will tend to remain stable and not produce acid. In contrast, if frambooidal pyrite were to be present, then it is expected to readily decompose and produce acid. On this premise, and in view of the natural limits of alkalinity imposed by the carbonate-bicarbonate geochemical reactions, the occurrence of acid mine drainage can be directly related to the occurrence of frambooidal pyrite within a coal seam and associated strata.

According to Fripsperger and Maevsky (1979) pyrite is reported to occur in minor quantities disseminated throughout the rocks of the Narragansett Basin, but visual inspection and chemical analyses of coal samples show low sulfur-bearing mineral contents. Frambooidal pyrite occurs as clusters of spheres of iron disulfide about 0.25 microns in diameter. Euhedral crystals and coarse grained crystals of the type reported in the Narragansett Basin, however, do not decompose rapidly enough to produce severe acid mine drainage. The occurrence of frambooidal pyrite has been correlated with paleogeographical environments and shown to be high in marine-influenced back-barrier and lower delta-plain deposits and poor in upper delta-plain and alluvial-plain deposits (Caruccio and Fern, 1974). Because the Narragansett Basin sediments are alluvial-plain deposits and have been metamorphosed and the coal is anthracite, little, if any
framboidal pyrite is expected to be present, and severe acid mine
drainage problems would not be likely (Fripieter and Maevsky, 1979).

Methodology to predict the occurrence of acid drainage has been
developed using simulated weathering tests on core samples (Caruccio and
Giedel, 1981). The procedures are additionally described by Caruccio et
al., 1981). It would be appropriate to apply these procedures and
develop predictions for acid drainage in the most likely coal producing
regions of the Narragansett Basin. The results would relate directly to
the requirement for control or treatment of mine drainage.

SUSPENDED SEDIMENT

Suspended sediment is a potential problem in waters originating in,
or passing through, coal mining regions. In general the sediment may
originate from two sources: 1) coal processing with water to remove fine
material from the coal and 2) surface soil erosion from stripped or
exposed land surfaces. In either case the sediment can be a serious
problem unless controlled.

Total suspended and settleable solids are primary causes of turbidity
(cloudiness). Turbid water affects aquatic life by reducing
photosynthesis are primary causes of turbidity. They also serve as a
transport mechanism for nutrients, pesticides, and other toxic
substances, which are readily absorbed onto clay particles. Suspended
solids are of special importance for drinking water, because suspended
matter can reduce the effectiveness of disinfection by creating areas
where bacteria do not come into contact with the disinfectant.

Fish and fish food populations are affected by suspended and
settleable solids in the following ways (Statewide Planning, 1979).
. fish may be killed directly, or their growth rate or disease
  resistance may be reduced;
. fish spawning and development of fish eggs and larvae may be
  impaired;
. natural movements and migrations of fish may be modified;
. bottom-dwelling organisms may be smothered;
. settled organic materials may remove dissolved oxygen from
  overlying waters.

The extent to which coal processing produces sediment is an
operational aspect which can be controlled by regulating the coal mining
and processing procedures. Solutions may range from performing the
washing operation at a location where the discharge is of no consequence
to a contained wash water recycle operation. The latter is by far the
best solution, since it is difficult to find an environment even in a
coastal area where turbidity would not have some adverse effect.

With regard to erosion and sedimentation in general, proper control
requires both short term and long term measures. Generally the most
critical period is during the initial construction and development phase
when large areas of surface are laid bare. Restoration of the affected
land areas should be deliberate programs and accomplished as rapidly as
possible.

The State 208 study (Statewide Planning, 1979) provides the following
pertinent discussion:

"The state's role in regulating erosion and sedimentation
impacts from construction generally is limited to grant
administration and assisting local governments. The major
state legislation dealing with soil and erosion control is
Chapter 2-4 of the General Laws of Rhode Island. This statute
creates a state Soil Conservation Committee (SCC) to offer assistance to the soil conservation districts, also established under the act. The SCC's powers are limited generally to offering assistance to the directors of the conservation districts, disseminating information throughout the state concerning the activities and programs of the conservation districts, providing technical assistance to the department of Environmental Management, and establishing uniform accounting and auditing procedures to be used by the conservation districts. The state conservation districts play a more direct role by assisting local communities in developing conservation programs, conducting surveys of renewable natural resources, preparing long-range conservation programs, and acquiring and purchasing land for conservation purposes. Neither the Soil Conservation Committee nor the district commissions have any direct regulatory authority, although the commissions may carry out preventive and control measures for the conservation of renewable natural resources on lands owned or controlled by the state, in cooperation with the state agency having jurisdiction over the area; or on other lands with the consent of the occupier of the land.

There are several other state statutes, however, that could potentially be used to control the impacts of erosion and sedimentation near high-quality water bodies. Chapter 46-14 of the General Laws, for example, prohibits any person from discharging any sewage, drainage, refuse, or other noxious material tending to pollute or corrupt any drinking water source. Erosion and sedimentation could be deemed a pollution
source for purposes of this act, and the Department of Health could require erosion and sedimentation control devices near drinking water sources. The fine under this act for a violation, however, is only $20 per day, and is not a strong deterrent to a polluter and applies only to pollution of drinking water.

A second act which could be used to increase the state's control over erosion and sedimentation is the state's water pollution control act. Chapter 4b-12 of the General Laws prohibits any person from causing pollution of the state's waters through the discharge of sewage. Sewage is defined quite broadly under this legislation and includes any substance which may be "injurious to public health or comfort, or which would injuriously affect the natural and healthy propagation, growth, or development of any fish or shellfish, ...or which would defile (the) waters." Although the act has been used primarily to regulate point sources of pollution, the procedures of this law could be used to regulate the erosion and sedimentation impacts from construction sites.

The major drawback in the existing regulatory framework, however, is its lack of comprehensiveness. There is no single regulatory program responsible for controlling the erosion and sedimentation impacts of construction, and only a limited number of communities have developed local controls. Existing state legislation is inadequate to implement the best management practices (discussed below) for control of erosion and sedimentation.
BEST MANAGEMENT PRACTICES FOR CONTROLLING EROSION AND
SEDIMENTATION FROM CONSTRUCTION SITES

Erosion and runoff of sediments can be controlled effectively and economically by proper planning of land-disturbing activities. Proper planning serves the following purposes:

- The time and area of exposure of disturbed ground surfaces to the energy of rainfall and runoff water are minimized;
- The angles for graded slopes and fills are limited to an angle no greater than that which can be retained by vegetative cover or other acceptable erosion control device or structure;
- The lengths as well as the angles of graded slopes are minimized to reduce the erosive velocity of runoff water.

In addition, the appropriate combination of best management practices (BMP's) for erosion and sedimentation control should be used at the site in accordance with the following procedures:

**Ground Cover** - A ground cover (such as mulches, grass, etc.) sufficient to restrain erosion should be applied on that portion of the disturbed area where further active construction is not being undertaken.

**Reduce Runoff Velocity** - All areas subject to erosion should be treated so that the velocity of runoff water is effectively reduced below that necessary to erode the materials. In addition to using natural vegetation and
mulches as flow impediments, mechanical measures (such as retaining walls, ditches, etc.) may also be applied.

Upland runoff - Upland runoff from upper watershed areas which would contribute to erosion at the construction site should be diverted from disturbed areas by dikes, ditches, downdrains, etc.

Runoff detention - Structures should be provided where needed to collect and detain runoff and trap sediment that would otherwise be transported from the site. Such structures include filter berms, straw bale barriers, and sediment detention basins.

Protection of downstream channels - Where increases in stormwater runoff velocity and volume are expected to result from facilities constructed, provision should be made for permanent protection of downstream channels from the erosive effects of increased flows. Stormwater flows should be managed to decrease the time and volume of runoff concentration by increasing infiltration on site, and by conserving natural drainage ways and providing wide, meandering vegetated channels with gentle gradients and side slopes. Naturally vegetated buffer strips along stream banks should be preserved to promote infiltration of runoff water. As recommended in the 208 water-related land use plan, the width of this buffer strip should be at least 100 feet.

Source controls - Erosion and sedimentation control measures that prevent transportation of sediments from a site area will also deter movement of solid wastes and other
pollutants, such as oils, metals, and pesticides that are adsorbed to soil particles. However, sediment controls will not prevent the passage of pollutants carried in solution. Adequate control of dissolved pollutants (such as nitrates, chlorides, metals, etc.) is therefore, dependent on proper application of materials and "good housekeeping" practices. These involve conservative use of fertilizers and pesticides, with special attention to applying them only to points of need, minimizing the quantities applied and prohibiting application in periods of weather extremes such as freezing conditions which render the ground impermeable and ensure runoff of materials. Washing facilities for equipment should be located and concentrated at specific points where draining waters can be collected in impervious holding ponds. Washing of finished surfaces to remove excess concrete or other chemical residues should be undertaken only after holding ponds have been provided to catch drainage waters. Waste quantities of paints, oils, and greases and other liquid and solid waste materials should be collected and transported to proper off-site disposal areas.

The particular measures which should be required for control of non-point source pollution from construction sites will depend on specific site characteristics, including topography, soil characteristics, vegetative cover, and climate. For a more complete description of erosion and sediment control options, see Recommendations for Erosion and Sediment Control During Land Use Change, The Southern New England Chapter, Soil Conservation Society of America, January.
REGULATIONS AND WATER LAW

Responsibilities

The prevention of water pollution traditionally involves all three levels of government. The federal government has served as the major source of treatment facility grants and technical assistance, and it has provided additional enforcement authority. State water pollution control agencies generally have been responsible for establishing basic regulatory and enforcement programs, water quality planning, surveillance of ground and surface waters, and administration of state aid for treatment facilities. Local governments have been principally responsible for installing and operating pollution control facilities and regulating land use.

More recently, and of direct relevance to mining control, the Office of Surface Mining (OSM) was created in 1977 after 5 years of discussions between the coal industry, environmental groups and many other interested parties. The primary purpose of the OSM was to write and administer the rules and regulations of a new federal law called Surface Mining Control and Reclamation Act, Public Law 95-87 (SMCRA). SMCRA was the first national legislation to attempt to control surface mining. In form, it is comparable to other environmental acts, such as the Clean Air Act. In approach, however, SMCRA is unique.

Unlike other environmental acts, SMCRA details specifically the goals of reclamation and precisely describes how those goals are to be met. Other environmental regulations set performance standards that industry can meet, usually using best available technology.

Among the purposes of the SMCRA is the provision of "a means for development of the data and analyses necessary to establish effective and
reasonable regulation of surface mining operations for other (than coal) minerals."

An important regulatory objective is the preservation of the hydrologic balance. Permits for mining will not be issued unless the effect of mining on the hydrologic balance is ascertained and mining operations are planned in a manner that minimizes adverse consequences. Detailed regulations have been promulgated to insure that the hydrologic balance is not adversely affected during mining operations and to insure that reclamation of the mined area is carried out in a manner that restores the hydrologic balance.

The United States Environmental Protection Agency (EPA) is the major federal agency responsible for implementing environmental programs, including water pollution. Enactment of the Federal Water Pollution Control Act Amendments of 1972 signalled a long-range commitment on the part of the federal government to clean up and maintain the purity of the nation's waters. This act, which was amended in 1977, provides for the abatement of water pollution and the prevention of new pollution. First, water quality standards are established by the state; then the standards are to be attained by limiting the pollution discharged into water by individual sources. The amount of pollution is regulated under the National Pollutant Discharge Elimination System (NPDES). The NPDES system requires a permit for all point discharges to surface water. A permit generally contains conditions designed to assure compliance with water quality standards and effluent limitations. The level of treatment required by a permit depends on the type and amount of pollutants permitted to be discharged (Statewide Planning, 1979).

Among programs the Environmental Protection Agency currently is administering are those mandated by the Safe Drinking Water Act, the Clean Air act, and the National Environmental Policy Acts.
A. The Safe Drinking Water Act delegates the regulation of the quality of drinking water supplied to the EPA and the states. The major provisions which relate to the safety of drinking water and coordinated water supply-wastewater treatment planning include adoption of national interim primary standards, proposed state underground injection control program regulations for designation of sole source aquifers, proposed regulations for organic chemicals, and research on water quality problems.

B. Under the Clean Air Act, the EPA set national ambient air quality standards, new source performance standards for new plants, and emission limits for existing stationary sources. Sludge, a by-product of most air quality control technology, must be disposed of carefully to avoid pollution of water.

C. The National Environmental Policy Act requires that all federal agencies prepare an Environmental Impact Statement for all major projects before commencing construction or operation. The impact of the proposed project on the environment including water supplied must be assessed and, if necessary, mitigating measures identified.

The State of Rhode Island has a number of departments, agencies, and boards concerned with planning, regulation, administration, and enforcement functions. The Department of Environmental Management (DEM) is the major state agency which has responsibility for water quality management. Two divisions of DEM, Water Resources and Land Resources, are responsible for controlling pollution from both point and nonpoint sources of pollution. The various programs administered by these divisions form the basic framework for the state's water quality management program. The major programs administered by DEM that address point sources of pollution are construction grant funding for wastewater treatment facilities, water quality monitoring, and review of EPA
discharge permits. UDM establishes water quality standards and monitors wastewater discharges (effluent) and instream (ambient) water quality. The results of the ambient monitoring program provide a basis for determining progress toward the attainment of water quality goals and standards. Effluent monitoring also is particularly important in establishing effluent load allocations, abatement programs, and compliance dates for wastewater discharge permits (Statewide Planning, 1979).

Although UDM is the primary state water quality management agency, several other offices also have responsibilities in this area. The Water Resources Board, consisting of nine (9) members representing both the public and state agencies, is charged with the development of public drinking water supplies. The Department of Health is primarily responsible for protecting drinking water supplies from contamination, and it tests water supply sources. The Coastal Resources Management Council (CRMC) has extensive authority over activities within or affecting the state's coastal region, including the protection of coastal wetlands from pollution. The CRMC adopted a coastal zone management plan in March, 1978 to protect the state's coastal region. It will implement the plan through its permit and regulatory powers. The Rhode Island Statewide Planning Program is the central planning agency for state government, and it is responsible for developing plans in several functional areas, such as land use and water quality management. Finally, the Solid Waste Management Corporation is responsible for developing strategies for resource recovery as an alternative solution to the state's solid waste management problems (Statewide Planning, 1979).
At the local level land use controls are the principal means available to regulate potential pollution causing activity. The relationship between land use regulations and water quality has been specifically recognized under the Federal Clean Water Act. Local governments in the Rhode Island 208 area receive the authority to regulate land use through the state's zoning and subdivision enabling acts, which delegate these powers exclusively to cities and towns. At the present time, all 39 Rhode Island cities and towns have adopted zoning ordinances, and all but two urbanized communities have subdivision regulations. Blackstone and Millville (Massachusetts) also have adopted zoning and subdivision ordinances (Statewide Planning, 1979).

While zoning is an issue peripheral to the study of hydrologic implications, the two are frequently related through anticipated impact. It should be noted that any development relative to mining would be in the industrial category. The vast majority of land in the Narragansett Basin is zoned as open space or residential (Statewide Planning, 1978); a small amount is industrial. This combined with a general high residential density in much of the Basin will necessitate early agreements with both the state and the municipalities involved by the prospective miner before any detailed planning effort takes place. A good initial reference is the State Housing Plan Report Number 24 (Statewide Planning).

Existing Regulations

The following discussion of the several federal, state, and local programs affecting the use of land for mining activity in Rhode Island is taken directly from the Rhode Island 208 study (Statewide Planning, 1979).

A. "Federal Programs
The relationship between land use and water quality is specifically recognized under Section 208 of the Federal Clean Water Act, which requires that the 208 plan establish a program to "regulate the location, modification and construction of any facilities... which may result in any discharge." This section also focuses on the institution of land use controls to minimize pollution from nonpoint sources, such as agriculture and construction.

The Safe Drinking Water Act of 1974 provides that federal funds be limited in areas where aquifers are in danger of contamination. The 208 land use recommendations are a means of helping to ensure that such contamination does not occur.

The Coastal Zone Management Act of 1972 provides for the development of management plans to protect the nation's coastal waters, shorelands, and inland waters which have a direct and significant impact on coastal waters. There are several relationships between coastal zone management planning and water quality planning, undertaken through Section 208 of the act. Section 307 of the Coastal Zone Management Act specifically provides that programs developed pursuant to the Clean Water Act will be incorporated as the water quality component of coastal zone management programs. This provision attempts to achieve compatible planning between the two programs, and a memorandum of understanding has been entered into between Rhode Island's 208 planning program and the state's coastal resources management agency. All proposals for activity in the coastal zone are evaluated in terms of their impact on water quality, among other factors."
8. "State Programs

There are several state laws aimed at protecting wetlands and shoreline areas. These include controls over intertidal salt marshes, coastal wetlands, and freshwater wetlands.

Intertidal wetlands are protected under Chapter 11-46.1 of the General Laws. Any person who

...dumps or deposits mud, dirt, or rubbish upon, or who excavates or disturbs the ecology of intertidal salt marshes, or any part thereof, without first obtaining a permit from the Department of Environmental Management shall be fined for each offense five hundred dollars ($500).

A violator may be required to restore the marsh to its original condition.

Coastal wetlands can also be protected under Sections 2-1-13 through 2-1-17 of the General Laws. The Department of Environmental Management is authorized under these sections to

"...designate coastal wetlands or parts thereof, the ecology of which shall not be disturbed and the use of which shall be restricted to those uses compatible with the public policy of this state as set forth in such order." The department, in adopting such an order, must consider the value of the coastal wetlands to the public health, marine fisheries, wildlife, and the protection of life and property from flood, hurricane and other natural disasters. No city or town can permit "the use of such restricted coastal wetlands contrary to such order."

There have been, however, several difficulties in implementing the Coastal Wetlands Act. An owner of land, subject to an order designating a coastal wetland, can "recover compensation for damage in an action filed in superior court
within two years from the date of recording such order." The money to be awarded for these damages is appropriated through a Recreational and Conservation Land Acquisition and Development Fund established in 1964, or it can be appropriated directly for the enforcement of the act. No special appropriations have been made, however, for the enforcement of the act, and the Recreation Fund has been inadequate to meet the potential cost of damages to owners. As a result, no order has as yet been issued under this act.

Freshwater wetlands, including marshes, swamps, bogs, and other types of wetland areas, are protected under the Fresh Water Wetlands Act of 1971, and the amendments to this act of 1974. The act prohibits the alteration of freshwater wetlands by excavation, drainage, fill and other activities without first obtaining a permit from the Department of Environmental Management and the approval of the local city or town council. A violator under this act may be required to restore the wetland to its previous condition, and he also is liable for a fine of up to $1000 for each violation.

The Fresh Water Wetlands Act differs from the Coastal Wetlands Act in several ways. Under the Fresh Water Wetlands Act, the Department of Environmental Management acts on individual permits, rather than issuing an order designating an area to be protected and the permittee uses. The 1974 amendments to the act also establish several criteria for the awarding of damages. The superior court may direct that compensation be paid if "...the proposed alteration would not essentially change the natural character of the land, would not
be unsuited to the land in the natural state, and would not injure the rights of others." The Coastal Wetlands Act does not contain any similar criteria, and protection under this act could routinely involve the payment of funds.

The Fresh Water Wetlands Act, Sections 2-1-9 through 2-1-25, also defines floodplains as areas adjacent to a river or stream which are likely to be covered with floodwaters resulting from a 100-year frequency storm. These floodplains are considered wetlands under the act, along with any area of land within 50 feet of the edge of a bog, marsh, swamp or pond.

Recent controversy over the application of the Wetlands Act has resulted in several changes to the permit process. The thrust of these changes has attempted to provide an objective determination of the application of the Wetlands Act to a particular site, and a more open process for the granting or denial of wetland permits.

Chap. 46-23 of the General Laws established the Coastal Resources Management Council (CRMC) to plan and coordinate activities in the coastal areas. Several specific types of activities over which the CRMC has jurisdiction are set out in the act:

- power generating and desalination plants;
- chemical or petroleum processing, transfer, or storage;
- minerals extraction;
- shoreline protection facilities and physiographical features;
- intertidal salt marshes; and
- sewage treatment and disposal, and solid waste disposal facilities.
The CRMC has adopted a coastal management plan in accordance with the national legislation. The 208 plan, when completed, will be included as the water quality element of this coastal plan. A memorandum of understanding has been entered into by the 208 project and the CRMC to ensure coordination of the two planning processes. The R.I. Coastal Resources Management Council has authority to regulate potentially polluting activities within coastal wetlands and contiguous land areas within 200 feet of these wetlands. The CRMC plan recognizes that sewage disposal and stormwater runoff occurring outside that 200-foot area can affect the quality of coastal waters, but coastal permits are required only for "major" activities which occur beyond the 200-foot boundary.

C. Local Program

Local governments traditionally have had the primary authority for regulating land use. This authority is granted to the cities and towns by the state zoning and subdivision enabling acts, which were adopted during the early 1920's. The acts set forth specific purposes for land use controls and describe the kinds of actions which can be taken.

Zoning - Zoning ordinances divide the land in a community into districts and specify the uses which are permitted in each. Every community in Rhode Island, as well as Blackstone and Millville, Massachusetts, have adopted zoning ordinances. A general zoning map for the 208 area is in the back of this report. In Rhode Island, most communities adopted their ordinances under the provisions of the general state zoning
enabling act, although several communities, such as South Kingstown, have special acts. The power to adopt a zoning ordinance rests with the city or town council. In most communities, the ordinance is drafted by the planning board, usually with the assistance of a professional planner, and reviewed by the town solicitor before it is enacted. The building inspector usually is the enforcement officer; a permit will not be issued for a structure not in conformance with the provisions of the zoning ordinance. The zoning board of review is authorized to grant variances from the requirements when "a literal enforcement of the provisions of the ordinance will result in unnecessary hardship..." and to grant special exceptions which are "in harmony with its general purpose" or are "reasonably necessary for full enjoyment of the property."

The zoning powers, as stated in the general enabling act, are as follows:

...to regulate and restrict the height, number of stories and size of buildings and other structures, the percentage of lot that may be occupied, the size of yards, courts and other open spaces, the density of population, the location and use of buildings, structures and land for trade, industry, residence or other purposes, and to prohibit or limit uses of land in areas deemed to be subject to seasonal or periodic flooding.

For any and all of said purposes said city or town council may divide the municipality into districts of such number, shape, and area as it may deem best suited to carry out the purposes of this chapter; and within such districts it may regulate and restrict the erection, construction, reconstruction, alteration, repair or use of buildings, structures or land. All such regulations shall be uniform for each class or kind of buildings throughout each district but the regulations in one district may differ from those in other districts.
The Rhode Island Supreme Court has held that city and town ordinances cannot exceed the authority conferred by the enabling legislation. Because these acts were drafted in the 1920's, many of the more modern zoning techniques are not mentioned, and it is questionable whether communities have the power to use many of these newer tools.

The most persistent controversy with regard to zoning is the so-called "taken issue." The Fifth Amendment to the U.S. Constitution provides protection for property owners: "...nor shall private property be taken for public use, without just compensation." Courts have held that a municipality cannot zone property in such a way that the owner is "denied all economic use" of the land. It is often difficult to determine at what point zoning restrictions constitute such an unlawful taking.

The takings issue fundamentally is one of balancing the rights of society against the rights of individual landowners. Because there is no certain position on these matters, courts have applied the takings principle in view of their understanding of current conditions. In thousands of cases, courts have been asked to determine whether a particular restriction went too far to be sustainable without compensation. Decisions and rationales have been widely divergent, and as a result, there is considerable uncertainty about how far restrictive powers can go before expensive compensation must be paid."
The basis of regulatory control under the Surface Mining Control and Reclamation Act are contained in the following quote (Seltz-Patash, 1980):

"Under the Surface Mining Control and Reclamation Act (SMCRA), surface mining and reclamation proceed together. First vegetation and topsoil (0-12 in [253-305 mm] in the west) are removed and stockpiled. Next the overburden (100-150 ft/20.2-45.7 m thick) is removed and stored next to the pit in piles (spoil ridges). At this point, each mine site must have sedimentation ponds and run-off diversion ditches constructed.

Next, rows (cuts) are dug up to 50 ft (15 m) thick, 1 mile (1.6 km) long and 15 to 200 ft (4.6 to 61 m) deep. The coal is drilled, blasted and removed. Each cut must be backfilled within 180 days after coal is removed, by law. Because the overburden expands when removed, the filled cuts have ridges which must be graded back to the original contour of the land. Finally topsoil is replaced and the land is seeded, mulched and the healing process begins.

SMCRA is designed to protect the land during mining and ensure that it is returned to its pre-mining condition—and this includes soil composition, vegetation and wildlife habitats, land contour and groundwater and aquifer flow."

The following are key issues in regulatory control of mining operations:

A. Establishment of baseline information areas proposed for mining must have their characteristics completely defined prior to commencement of mining operations to avoid subsequent controversy over restoration.

B. Detention and monitoring of water leaving the mine area is essential to ensure downstream water quality during operations. In this regard, diversion channels and sedimentation ponds are the heart of the operational regulatory scheme.
C. Groundwater quality control by adequate design of dewatering and monitoring systems. As with all other regulatory practices, it is very important that monitoring with shut down authority be accomplished by parties completely independent of the mine operator.

D. Post mining planning and restoration is essential to the future use of the mined area (Green, 1981). The land mined must be returned to other productive uses when mining is complete. But this can be done effectively only if a coherent plan is developed before mining operations start.

Proposed Mining Controls

In order to protect the public and the environment, certain hydrologic aspects must be included in mining controls. Such controls must be a part of the planning, operation and post-operation phases of mining. The main elements which should be included in any mining rules and regulations are:

- Establishment of baseline data for determination of premining water quality and quantity.
- Prior approval of mining schemes and detailed evaluation of probable environmental impact.
- Design and establishment of monitor systems to ensure that adequate surveillance can be maintained.
- Assurance that operational controls are adequate to maintain hydrologic balance in the mining region.
- Knealing of exploration holes to preclude cross flow contamination of groundwater.
Acceptable water quality of surface water and groundwater moving from the site. Quality considerations must include both dissolved and suspended loads.

Procedures for maintenance of water table levels in areas in proximity to mining operations.

Procedures for maintenance of stream flow in areas in proximity to mining operations.

Procedures for special protection of wetlands.

Provisions for restoration of region after mining has ceased.

All of the foregoing are adequately covered in Pennsylvania bulletin, Volume 10, Number 51, (Department of Environmental Rules and Regulations Concerning Coal Mining). This document can be used as a model for Rhode Island mining regulations, with certain additions hereafter described.

A unique feature of the Narragansett Basin is the large amount of salt water shoreline included in the region. This necessitates special measures to avoid salt water intrusion problems. Provisions should be included in the Rhode Island mining regulations to:

1. establish baseline information on the location of the fresh water-salt water interface in the ground in coastal areas.

2. evaluate the effect of the proposed mining operations, especially dewatering, on the fresh water-salt water interface.

3. establish a coastal groundwater monitor systems to ensure protection for present and future groundwater users.

The following specific additions to adapt the Pennsylvania mining regulations to Rhode Island are recommended:

1. Sections 87.1, 88.1 and 89.5, "Definitions."

   add (x) Coastal ground water - ground water in hydrologic balance with a salt water boundary.
2. Section 87.45a, "ground water information"
   Section 88.25a, "ground water"
   
   add (x) The position and limits of the fresh water - salt water interface in coastal areas.
   add (x) Water Table fluctuations on a seasonal and daily basis in coastal areas.

   Section 89.92, "Surface and ground water monitoring"
   
   add (x) Ground water monitoring in coastal ground water shall include multi-level sampling sufficient to describe movement and limits of the fresh water - salt water interface.

CONCLUSIONS

Most of the Narragansett basin is served by public water supply not likely to be affected by mining activity; however, numerous active private and industrial wells are present which could be adversely affected by mining activity.

In the coastal region of the Narragansett basin, lowering of the water table could cause salt water intrusion with severe consequences to wells in the affected area.

Any effect by mining on ground water levels or quality can be of great importance to ponds, lakes and streams because of the likelihood of hydraulic connections.

Because of the lack of framoidal pyrite in the Narragansett basin rocks, severe acid mine drainage problems are not likely. However, investigation and acid drainage predictions should be made on a site specific basis.

Suspended sediment contamination of surface waters is a potential problem in waters originating in, or passing through, coal mining regions. Sediment from coal processing and surface erosion must be controlled.
Adequate control of mining operations and protection of Rhode Island citizens from adverse consequences while still permitting reasonable exploitation of coal resources will necessitate detailed involvement and careful planning by both state and municipal agencies.

It is essential that the prospective miner produce complete plans for both operational and post operational phases of mining prior to commencement of mining.

Collection of baseline data before operations begin, and continuous monitoring during and after mining is essential to assessing and controlling the environmental impact of mining.

As compared with other states, such as Pennsylvania, where comprehensive mining regulations exist and can be used as model, Rhode Island is unique in that salt water bodies exist within a few miles of any prospective mining operation. This requires that Rhode Island mining regulations include specific provisions to guard against ground water contamination by salt water intrusion.

ACKNOWLEDGMENT

Special thanks is due to the Providence Office of the U.S. Geological Survey for assistance provided in obtaining well data and geologic information. Also greatly appreciated is the water supply system information provided by many municipalities and agencies throughout the State of Rhode Island.
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APPENDIX A

GROUNDWATER CHARACTERISTICS FOR WATERS
BEARING FORMATIONS OF THE NARRAGANSETT BASIN
APPENDIX A

GROUNDWATER CHARACTERISTICS FOR WATER
Bearing Formations of the Narragansett Basin

SEDIMENTARY ROCKS

The following is taken from Lang (1961):

"The Carboniferous sedimentary rocks of Rhode Island also have a porosity of less than 1 percent, and the only openings capable of transmitting water are the secondary openings along joints, fractures, and bedding planes.

A summary of the yield of 418 wells tapping sedimentary rocks in Rhode Island indicates an average yield of 30.9 gallons per minute and a range in yield from less than 1 to 500 gallons per minute. Thus, the average yield from sedimentary rocks as a whole is almost three times as great as from the crystalline rocks. Three percent of ten wells yielded less than 1 gallon per minute. Forty-nine percent yielded from 1 to 10 gallons per minute, and 32 percent yielded from 11 to 50 gallons per minute. Only 16 percent yielded more than 50 gallons per minute. Small and large yields of wells, as in the crystalline rocks, were scattered throughout the State.

Depths of wells in Carboniferous strata range from 38 to 1,436 feet and average about 277 feet. Such wells are, on the average, more than 100 feet deeper than those tapping crystalline rocks. This greater average depth is due partly to topographic location. The sedimentary rocks are in the
low-lyingNarragansett and Woonsocket Basins covered in most places by 50 to 100 feet of overburden. Thus, wells in sedimentary rocks may also penetrate thick deposits of overburden.

Many wells have been drilled into the Carboniferous strata in Rhode Island. Most of them have produced enough water for domestic, farm, and small industrial use. As only 16 percent of 418 wells penetrating Carboniferous sedimentary rock had reported yields of more than 50 gallons per minute, they cannot be considered sources of large supplies of ground water for municipal and industrial use."

Giershenk (1959) provides the following observation of interest:

"In the summer of 1955 there was opportunity to examine closely the Pennsylvanian sedimentary rocks then exposed along the line of a sewer tunnel under construction in Pawtucket. The 8-foot tunnel passes beneath the large till-bedrock hill in the northeast corner of the quadrangle and lies beneath the line of test borings Paw. 310, 307, 305, 302 and others extending northeastward to Pleasant Street. The tunnel is 4,980 feet long and penetrates interbedded sediments, principally dark-gray sandy shale, shaly sandstone, and thin coaly beds of the Rhode Island formation. Locally, at the eastern end, red sandstone of the Wamsutta formation was penetrated. The bedding of the sedimentary rocks strikes roughly north and dips 35 to 50 degrees east. Two major joint systems are evident. The greater number of joints strike north and dip generally about 35 degrees or about 50 degrees west, although a few dip as much as 80 degrees west. Other joints strike north and dip roughly 60 to 80 degrees east. The spacing between joints usually ranges from
a few feet to 10 feet and the width of opening ranges from that which was scarcely visible to a sixteenth of an inch. Water was observed to be percolating along both bedding planes and joints, presumably coming largely from the overlying unconsolidated glacial deposits."

GLACIAL TILL

The following is taken from Lang (1961):

"The till in Rhode Island is relatively impermeable and, like clay, yields water very slowly, the rate of yield depending upon the proportion of coarse material to fine material. The composition of till may vary considerably from place to place. Some observers report a great contrast in the character of the till in the town of Cumberland west and east of Uxbridge Hill Road. To the west the till is underlain by metamorphosed igneous and sedimentary rocks and has a somewhat sandy or stony character, whereas to the east the till overlies shales of Carboniferous age and is more clayey. More permeable lenses or local layers of stratified sand and gravel occur in till or immediately between the till and the underlying bedrock. Doubtless, many of the wells listed as penetrating till obtain most of their water from such permeable layers.

Till, in one form or another, generally yields sufficient water for household and farm use. Groundwater is usually obtained from the till by means of dug wells, which offer the advantage of a large storage area and comparatively inexpensive cost of construction. The water level in such shallow dug wells may reach low stages in late summer and early fall. Records
show that many till wells become dry each year late in the summer. As a result, shallow dug wells are gradually being replaced by deeper drilled wells tapping bedrock.

In general, wells finished in till average about 20 feet in depth and yield less than 2 gallons per minute, unless layers of sand and gravel are penetrated. About half the water pumped from farm and household wells in the State is obtained from the till."

GLACIAL OUTWASH

The following is taken from Lang (1961):

"Outwash deposits are the most productive aquifers in Knoxe Island because of the abundance of well-sorted coarse-grained particles. Such deposits yield water readily to drilled and driven wells. Depositional conditions during the Pleistocene epoch were varied and relatively complex. As a result the character, and consequently the permeability, of the outwash varies considerably within relatively short distances, in some cases abruptly changing from coarse-grained to fine-grained materials. The finer outwash deposits, clay and silt, are nearly impervious. Data for wells ending in outwash indicate a range in depth from 20 to more than 200 feet and a range in yield from to 3 to 2,700 gallons per minute.

The coarser stratified beds of sand and gravel are the most important potential sources of large supplies of ground water in the state. Unfortunately, only a relatively small part of the state is underlain by such beds. The principal areas in Knoxe Island that are underlain by coarse stratified deposits include
the valleys of the major streams, except in Newport County.

Where present streams flow directly over benches of coarse
outwash, infiltration of river water can be induced by locating
wells adjacent to the streams. In such locations, individual
wells may yield as much as 2,000 gallons per minute, or even
more. For example, a small area of outwash along the Hunt River
in Warwick and East Greenwich yields several million gallons of
water daily without causing a progressive decline in water
levels. Also, the Kent County Water Authority well field,
several hundred feet from the Hunt River, yields more than 1
million gallons daily without causing a decline of water
levels. Less than one-quarter of a mile from the Kent County
wells and also near the Hunt River, the supply wells for Quonset
Point Naval Air Station also withdraw more than 1 million
gallons per day without progressive lowering of water levels.
Undoubtedly the yield from these well fields represents but a
small part of the total capacity. In Rhode Island, ground-water
levels under natural conditions are usually above stream levels,
and infiltration through stream beds into the ground occurs only
for short periods at times of high streamflow. However, where
groundwater levels are lowered below stream levels by pumping
from wells, as is the case along the Hunt River, the water-table
gradient is reversed and water flows from the river into the
ground. Under such conditions streamflow is a major factor in
groundwater recharge. Pumping may also result in more recharge
during highwater stages by providing more storage space in the
aquifer, even in areas where recharge is not induced during
periods of lower streamflow."

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APPENDIX B

WELL RECORDS FOR RHODE ISLAND

TEST HOLES DRILLED IN 1976-77
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- **Survey:** Site No.
- **Remarks:**
- **Notes:**
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### Field Water Quality Measurements

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- [Notes on Site Data]
- [Additional Notes on Water Quality]
- [Special Observations]
- [Environmental Considerations]
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2. Type of Study: [Code Info]

3. Frequency of Collection:
   - [Frequency Info]

4. Type of Log: [Type Info]