SALT WATER INTRUSION IN THE UNITED STATES

Robert S. Kerr Environmental Research Laboratory
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THE UNITED STATES

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

William C. Galegar
Director

ABSTRACT

Salt water intrusion, from one or more sources outlined in this report, has resulted in degradation of subsurface fresh water aquifers in 43 states. Numerous case histories delineating current problems exist, providing adequate documentation of the seriousness of salt water intrusion.

Waste from municipal and industrial sources entering natural streams or reservoirs are responsible for the more visible types of pollution; their detection is rapid, their source can usually be identified, and their elimination will result in rapid natural improvement of water quality. In contrast, the clandestine movement of salt water through a fresh water aquifer continues, defying early detection, concealing its origin, and creating long-term problems with expensive remedies.

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ACKNOWLEDGMENT

The need for this report was conceived by Mr. Edmond P. Lomasney, Regional Representative, Office of Research & Development, EPA Region IV, Atlanta, Georgia. He guided its development to conform with the needs of that Region.

Since its original preparation in January 1975, this report has been widely accepted and acclaimed, as can be shown by the continued and increasing requests for copies. The Robert S. Kerr Environmental Research Laboratory acknowledges with appreciation such favorable response which has resulted in this publication of "Salt Water Intrusion in the United States."

INTRODUCTION

GENERAL

The earth, concealing a lense of fresh water, was uniquely designed so man, requiring fresh water could exist. Then man, in his impatient pursuit of progress, created a demand on this resource exceeding the supply plus natural recharge. Where salt and fresh water zones are hydraulically connected, salt water intrudes as fresh water levels decrease thereby destroying the potability of the aquifer. In areas where subsurface reservoirs thus defied destruction, contaminants have been injected into them, exemplifying man's continuing disregard for his environment.

Contaminated ground-water reservoirs are not visible, give off no odor, and are not associated with fish kills; consequently, it has been difficult to generate interest in water pollution in the subsurface environment. Slow but sure, degradation of ground water continues while the seriousness of aquifer pollution has often been downgraded by environmentalists and policy makers who have directed their efforts to the more sensational forms of pollution.

GROUND-WATER USE

Conservative estimates indicate that subsurface water supplies 50 percent of the national population and 95 percent of the rural population. Some states depend on ground water for over 85 percent of their public water supply while 20 percent of the total United States water demands are met by subsurface supplies.

POTENTIAL PROBLEM AREAS

The U. S. Public Health Service in 1962 placed the limit on public drinking water supply at 500 ppm dissolved solids. Approximately two-thirds of the conterminous United States is underlain by aquifers known to produce water containing at least 1,000 ppm dissolved solids, and beneath most of these aquifers are zones containing mineralized water of 10,000 ppm and above. Areas contained in the remaining one-third are believed to contain mineralized water, but verification by well drilling has not been completed. Mineralized water, the majority of which is of the sodium chloride type, situated under or adjacent to most fresh water aquifers, constitutes a potential problem of salt water encroachment into fresh-water aquifers throughout the United States.

GROUND-WATER POLLUTION

In an effort to determine the magnitude of the problem of salt water intrusion, the American Society of Civil Engineers prepared a report in 1969 (1). From questionnaires sent to all 50 states, 43 indicated problems with salt water intrusion. Condensed from a table in this report is a summary of the types of salt water intrusion problems and number of states affected.

Number of States Affected	Type of Salt Water Intrusion
27	Lateral intrusion caused by excessive pumping
11	Vertical intrusion caused by excessive pumping
8	Improper disposal of oil field brines
6	Intrusion caused by faulty well casings
5	Surface infiltration
5	Layers of salt water in thick limestone formations
2	Vertical intrusion caused by dredging
2	Irrigation return flow

In this report, it was noted that the most acute problems were associated with metropolitan areas along the coast. In most of these areas, fresh water aquifers are hydraulically connected to the ocean or brackish waters of estuaries (Figure 1). Heavy demands on subsurface water supplies in large metropolitan areas or industrial complexes are generally responsible for fresh water aquifer contamination. When fresh water is extracted at a rate greater than natural recharge, salt water intrudes up-dip contaminating wells inland from the coast.

While salt water encroachment in inland areas affects fewer people than coastal intrusion, salinity problems from a number of man-made and natural sources are widespread, directly affecting 22 inland states. Problems in inland areas have received relatively little publicity although they are almost as numerous as coastal incidences of intrusion.

Salt water intrusion is characterized by movement of saline water into a fresh water aquifer through hydrodynamic changes of the system usually caused by man. Salt water and fresh water often share the same formation.

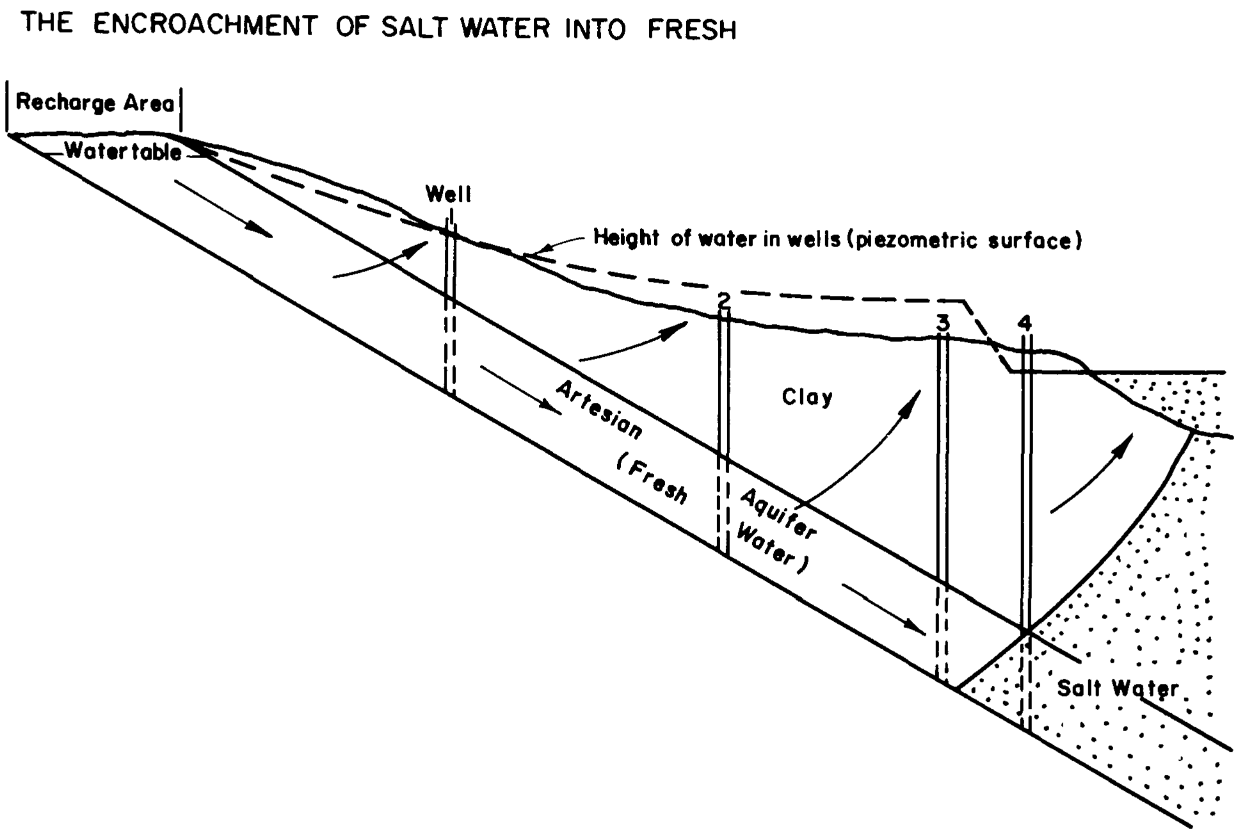


Figure 1. Idealized cross-sectional diagram showing relationships between salt water and fresh water where coastal artesian aquifer crops out beneath the sea at some depth. This might be almost anywhere along the Atlantic Coast from Long Island, N.Y., to Florida, along the Gulf Coast from Florida to Mexico, or along parts of the Pacific Coast. Similar hydrologic conditions occur on some of the Hawaiian islands and elsewhere. The artesian aquifer crops out inland from the shore where it is recharged by rain. In this area the aquifer has a free air-water contact (water table). Downdip the aquifer is covered by relatively impermeable clay, and the confined (artesian) water rises higher than the top of the aquifer. The level at which it stands in wells defines the piezometric surface. Note abrupt fall of the piezometric surface between wells 3 and 4, because well 4 ends in the zone of contact with salt water (3).

hydraulically connected yet delicately separated by the physical difference of specific gravity. Fresh water being less dense will occupy the upper reaches of a formation, retaining its identity if undisturbed (Figures 2 and 3).

Few incidences of salt water intrusion can be attributed to natural phenomena. Man's activities, primarily pumping more water from an aquifer than can be naturally replenished, are responsible for destroying the hydraulic continuity between fresh and saline waters.

Intrusion problems, created by excessive demands on subsurface reservoirs, are further complicated by natural or man-made avenues for salt water movement. Faults (Figure 4), unconformities (Figure 5), improper oil exploration (Figure 6), canal construction (Figure 7), and channel dredging all provide areas of possible communication. In many cases, the causes of salt water intrusion are interrelated, complicating their indentification and delaying their remedies.

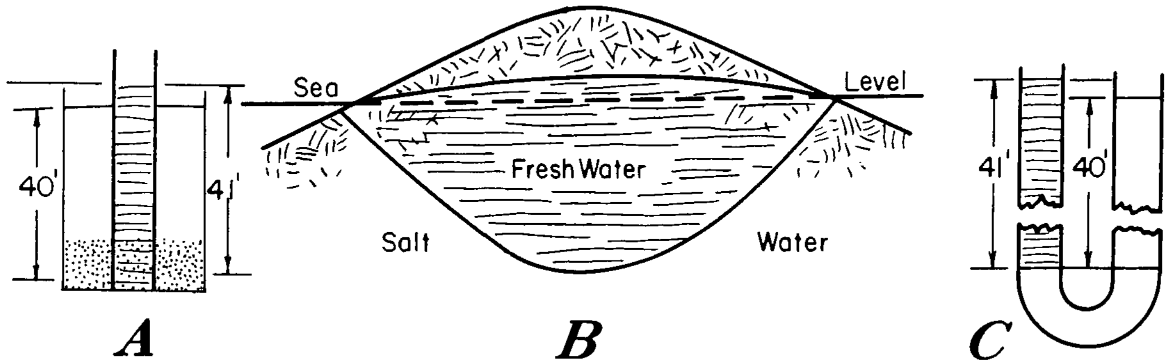


Figure 2. Three diagrams showing the relation of salt water to fresh water, according to the Ghyben-Herzberg principle. (A) Small, open-bottomed tube containing fresh water is placed in salt water and sand of larger container. Sand is indicated in diagram by stippling. Fresh water is free to move out but does not move beyond a point of balance with heavier salt water. Fresh water stands above salt water. (C) U-tube contains fresh water in left-hand side and salt water in right-hand side. As in (A), the fresh water stands higher than the salt water, 41 units high to 40 units high. (B) Idealized cross section of permeable island in sea. Here rain water has seeped into the sand and produced a lens of fresh water that has depressed the heavier ocean water. The fresh-water lens floats in and on the salt water much as an iceberg floats on the ocean with most its mass submerged. Periodic rains replenish the fresh-water lens (3).

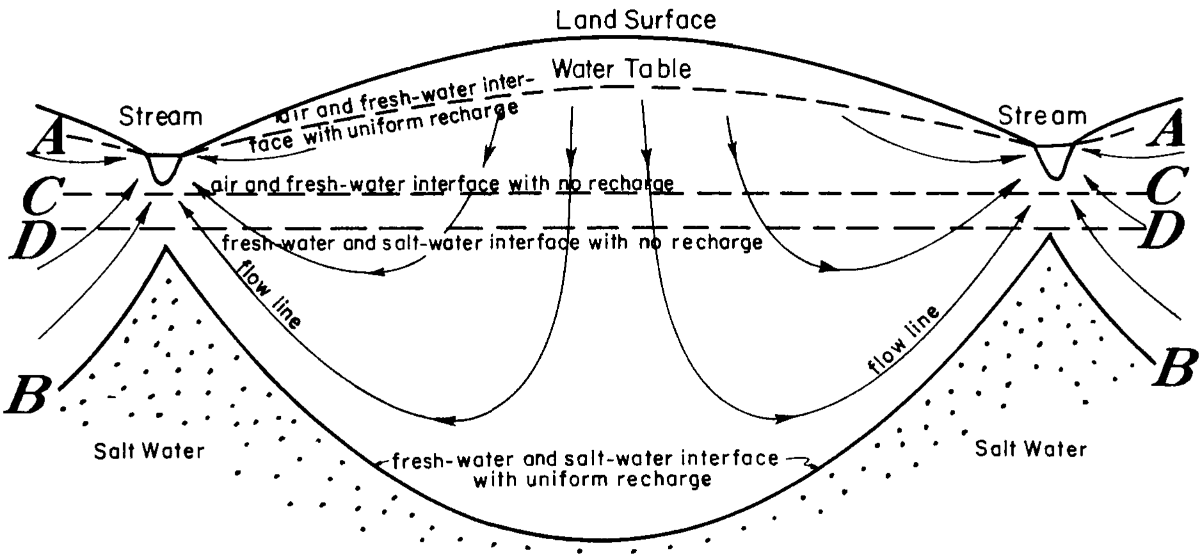


Figure 3. Idealized cross section showing interface relations between fresh water and salt water in a uniformly permeable aquifer. Two streams cut the land surface; and in times of sufficient rainfall when the water table is high, they intersect the water table and drain away the ground water. This condition is shown by the water table line A-A. Given no recharge, the water table sinks below the reach of the streams, line C-C. Salt water below the fresh water reacts for the condition of recharge as shown by line B-B, and the fresh water above flows downward and outward, as indicated by the arrows. Salt water below the fresh water reacts for the condition of no recharge, as shown in line D-D (3).

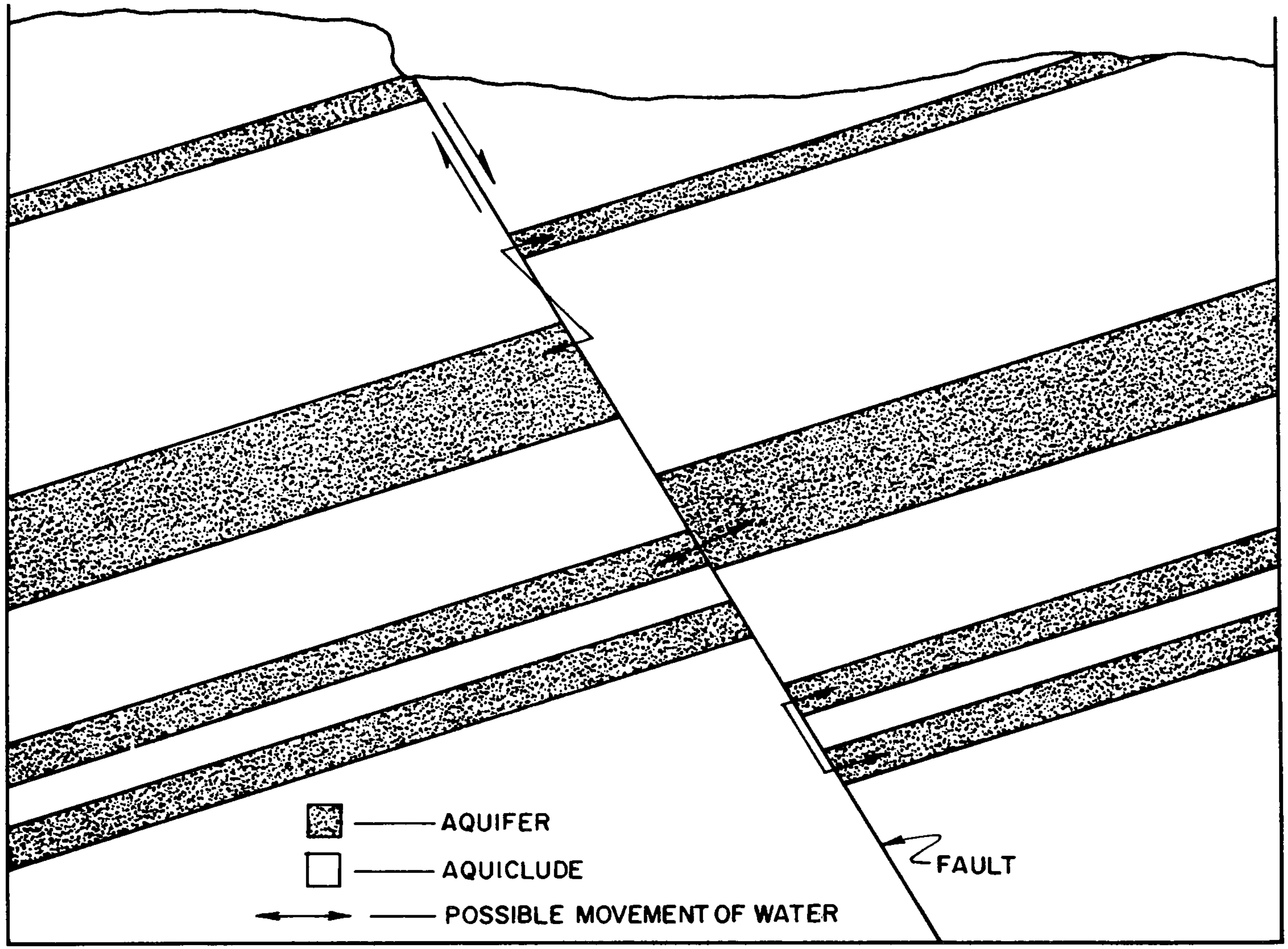


FIGURE 4 - SCHEMATIC DIAGRAM SHOWING CONNECTION OF AQUIFERS THROUGH FAULTS

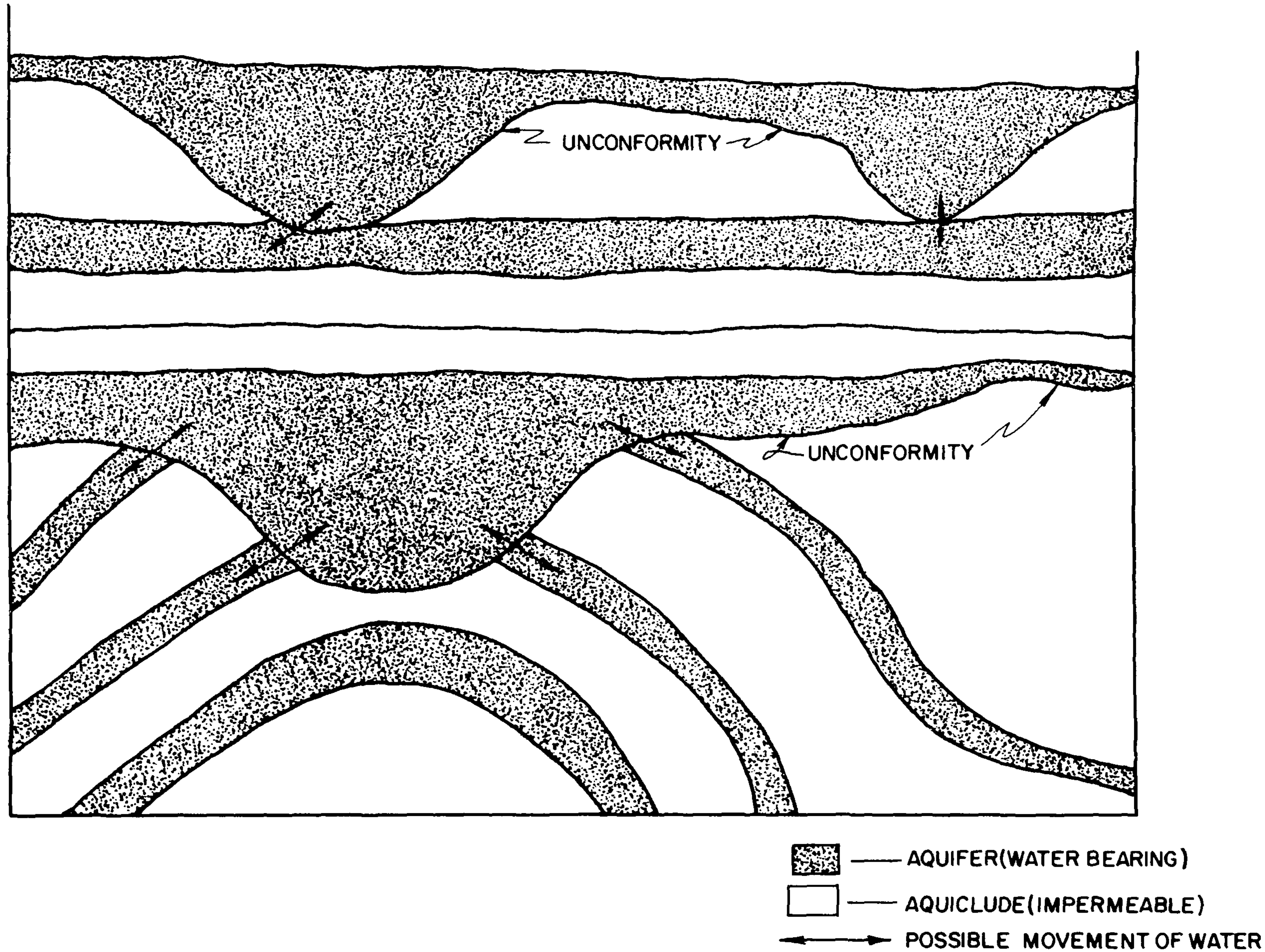


FIGURE 5 - SCHEMATIC DIAGRAM SHOWING CONNECTION OF AQUIFERS THROUGH UNCONFORMITIES

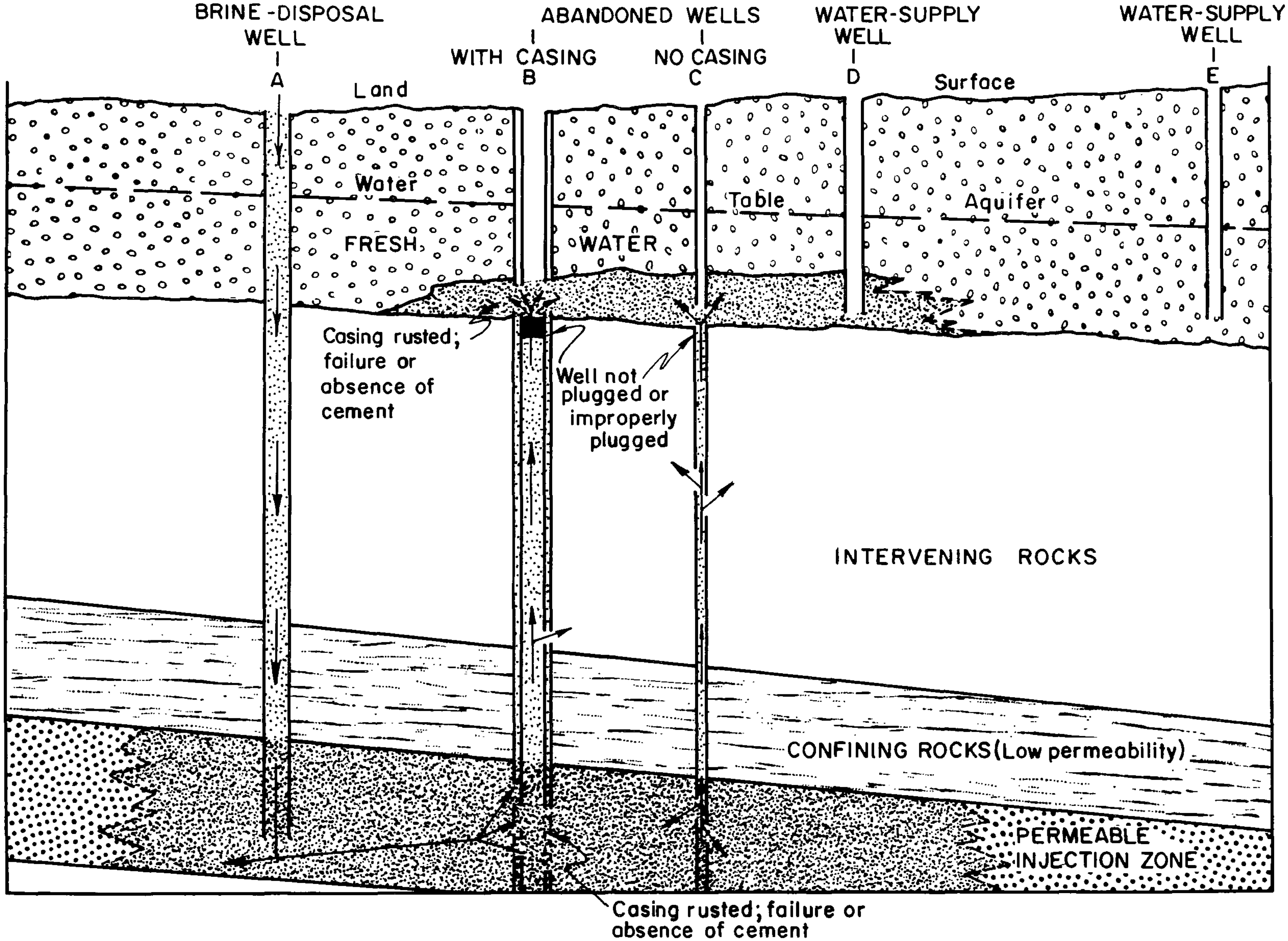
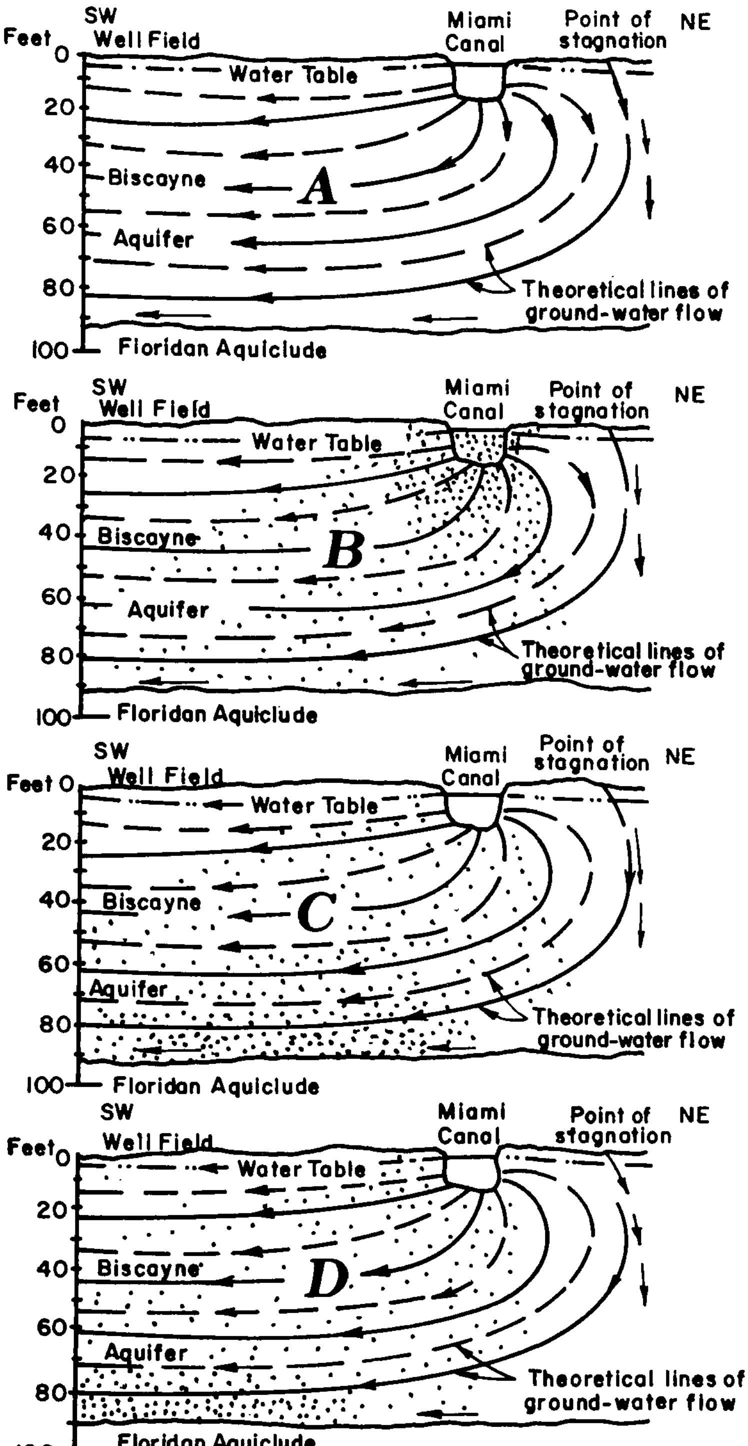


FIGURE 6 – SCHEMATIC DIAGRAM SHOWING HOW SALT WATER MIGHT ENTER A FRESH-WATER AQUIFER THROUGH ABANDONED WELLS



(A) Canal contains only fresh water and because of pumping nearby stands higher than adjacent water table. Water moves from canal into aquifer toward well field, to left side of illustration.

(B) Salt water moves into canal and leaks out of sides and bottom of channel, the greatest concentration of salty water at first being immediately under the canal.

(C) Fresh water has replaced salty water in canal and salt water in Biscayne aquifer is now cut off from its source. It sinks to base of aquifer and creates a salt water mound having highest chloride at bottom of mound. Mound moves to southwest, in direction of the local ground-water gradient.

(D) Flattened out and greatly diluted mound of salty water has moved into well field where it will be removed with municipal water.

DENSITY OF STIPPLING REPRESENTS
DEGREE OF SALINITY

Figure 7. A diagrammatic cross section illustrating salt-water encroachment by canal water in Miami, Florida (3).

MECHANISMS OF INTRUSION

REVERSAL OR REDUCTION OF GRADIENT

Salt water intrusion of this type while occurring in inland areas is most common along the coast of the United States. Potential salt water intrusion exists in all areas where fresh and salt water share the same aquifers separated normally by natural equilibrium.

Under natural conditions along the coast, subsurface fresh water will flow from elevated land areas to the ocean (Figure 1). Similar flow patterns exist in inland areas associated with estuaries or salt-bearing streams (Figure 8). Normally, sufficient pressure exists in the fresh water aquifer to counteract the tendency of salt water to move inland or laterally from streams or estuaries.

As fresh water levels are lowered by excessive pumping, a cone of depression is formed, reversing the gradient and allowing salt water to enter original fresh water zones.

DESTRUCTION OF NATURAL BARRIERS

Removing material of low permeability while dredging coastal waterways has resulted in salt water infiltrating into fresh water aquifers. Similar problems have been created by the construction of new coastal waterways which expose permeable materials, transverse fault zones, or other natural barriers. Oil exploration or deep mining practices which breach the confining layer between fresh and salt water aquifers provide additional avenues for intrusion. Salt water zones once penetrated can travel up or down poorly cemented, broken, or deteriorated well casings or within mining shafts to fresh water zones.

DISPOSAL OF WASTE SALINE WATER

There are several techniques of brine disposal which can result in the contamination of fresh surface or underground water. Saline wastes discharged to a stream or an unlined evaporation pit has the potential of infiltrating into a fresh water zone. Subsurface disposal of pollutants, especially salt water, have created serious problems inland as well as in coastal areas. Since these disposal wells penetrate zones of both fresh and salt water (Figure 6), problems occur when injection wells constructed in old fields, where abandoned wells have been improperly plugged, permit direct communication between the injection zone and the fresh water aquifer. In some areas, the structural consistency of the intervening zone separating the fresh from the saline formation is inadequate due to natural fracturing, thus permitting vertical intrusion.

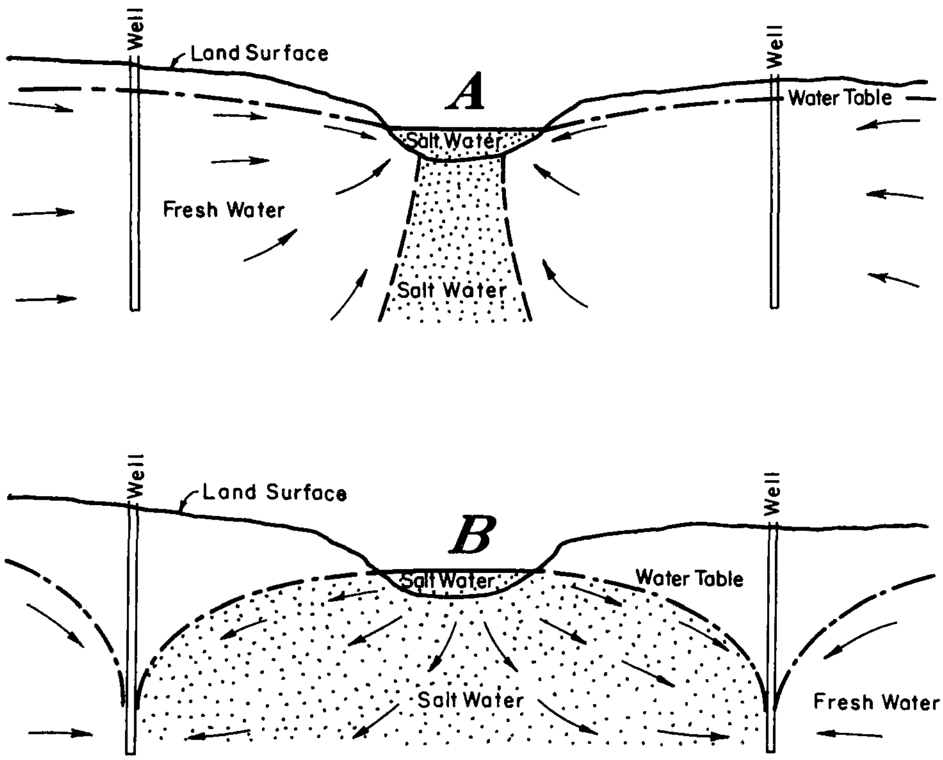


Figure 8. This diagram shows the ground-water conditions near a coastal stream that carries salty water in its channel. The arrows indicate the direction of ground-water flow. Salt water underlies the stream channel as a trapezoidal prism. (A) Movement under natural conditions before pumping takes place. (B) Movement during pumping of ground water. A cone of depression surrounds each pumped well, the water table is depressed, and salty water encroaches into the aquifer (3).

OIL PRODUCTION

Salt water intrusion affecting the inland part of the United States is largely due to oil exploration. In search of oil and gas in the United States over one million holes have been drilled which penetrate both fresh and salt water formations; these holes represent an equal number of communication possibilities which could adversely affect ground water. Documented cases of ground-water pollution from exploration activities lend credence to the fact that, when there are a million chances for failure, failure will occur.

In 1963, the Texas Water Pollution Control Board conservatively estimated that for every gallon of oil produced, 2.4 gallons of salt water was recovered. In 1970, 3.5×10^9 barrels of oil was produced in the United States; these figures will provide an indication of the magnitude of the problem of brine disposal. With the recent threefold increase in the price of crude oil, secondary recovery operations utilizing the salt water injection technique have been drastically increased. This type of production, in addition to a general increase in the national production, will increase the water-oil ratio of produced fluids possibly one order of magnitude.

Various states have enacted laws and published guidelines to prevent pollution from oil exploration and production. Properly followed, these would adequately control pollution from current activities; however, the administration and enforcement of these laws are inadequate in many areas. Compounding the problem associated with this industry is the lack of technology necessary to locate polluting wells which have been improperly plugged or abandoned. Legal responsibility for these wells drilled over the past 50 years cannot be determined, thus the burden of correcting the problem is on the state or landowner.

Salt water intrusion from past or present oil and gas exploration and production creates serious social, economical, and legal problems similar in many respects to aquifer contamination from other sources.

CONTROL TECHNOLOGY

Current technology has failed to provide a means of early detection of salt water intrusion into potable aquifers. Case histories are very similar. Supply wells which had for years produced fresh water for domestic, industrial, or agricultural purposes suddenly turn salty. Detection in most cases occurs after several miles of a fresh water aquifer has been severely contaminated. The economic feasibility of aquifer reclamation in many cases does not exist. The ground-water resource must therefore be abandoned and a search for surface water supply initiated.

Domestic, agricultural, and public water supplies of entire cities have been destroyed by the various types of salt water intrusion. Multimillion-dollar reclamation projects, funded by taxes or revenue bonds, can be developed by metropolitan areas affected. This avenue of relief does not exist in rural areas since domestic or agricultural supply wells constitute a considerable investment for rural families, the loss of which results in financial chaos. Abandoned rural homes and productive farmlands provide adequate testimony to this fact.

CURRENT CONTROL EFFORTS

Major efforts directed at controlling salt water intrusion are now underway primarily along the East and West Coast and the Gulf of Mexico. Several successful projects are now in operation while others are still in the planning or observation stages.

For example, salt water intrusion detected in the mid-1940's in the Los Angeles area has been reversed. This was accomplished by the injection of fresh water through a line of wells paralleling the coast, thus forming a mound of fresh water, acting as a barrier against sea water intrusion.

While analyzing water from three new wells near Terre Haute, Indiana, in 1955, it was discovered that the chloride was 550 ppm. Normal concentration of this aquifer had been about 16 ppm. A local study by the Indiana Department of Conservation and the U. S. Geological Survey identified the problem as an unplugged oil test hole 2,000 feet from the supply wells. To remedy this problem, the oil test hole was properly plugged and in an effort to evacuate the salt water from the fresh water aquifer, pumping of the supply wells was initiated in August 1956. By October 1958, after intermittent pumping of 7,000 hours at 800 gpm, the chloride concentration in the aquifer (14 to 62 ppm) was approaching normal.

These two successful control methods exemplify the current efforts underway and were selected to indicate the time and funding necessary to control or reverse salt water intrusion.

Listed below is a brief summary, outlining the various types of salt water intrusion problems and current options of control.

Lateral Intrusion Caused by Excessive Pumping (Coastal and Inland Areas)

(1) Reduce pumping
(2) Relocate wells

  (a) Move wells inland
  (b) Disperse wells to eliminate areas of intense pumping

(3) Directly recharge aquifer
(4) Fresh water recharge into wells paralleling the coast, forming a hydraulic barrier
(5) Create a trough parallel to the coast by evacuating encroaching salt water from wells

Vertical Intrusion

(1) Reduce pumping
(2) Disperse wells to eliminate areas of intense pumping
(3) Drill scavenger wells to evacuate salt water, thus reducing the pressure on the salt water zone

Improper Disposal of Oil Field Brine

(1) Eliminate surface disposal
(2) Regulate subsurface disposal
    (a) Select proper receptive formations
    (b) Use sound engineering techniques
    (c) Locate and properly plug abandoned wells in injection area

Intrusion Caused by Broken or Corroded Well Casings

(1) Locate and plug faulty wells

Surface Infiltration

(1) Eliminate source and prevent reoccurrences

Layers of Salt Water Existing in Thick Fresh Water Formations

(1) No remedy; well may be relocated, if feasible

The above outline of current treatment methods used in controlling salt water intrusion is stated briefly. All methods listed have been used with varying degrees of success. The following Table 1 lists in abbreviated form the location, encroachment problem, treatment utilized and results of treatment application throughout the United States. For detailed information concerning a particular area of interest, local authorities should be contacted.

TABLE 1.--REPRESENTATIVE EXAMPLES OF SALTWATER INTRUSION[1]

Location (1)	Nature of problem (2)	Corrective measures taken (3)	Outlook (4)
ALABAMA			
Mobile-Gulf Coast	Lateral intrusion from Mobile River caused by intensive pumping	Pumping curtailed; deeper wells for fresh water	Status quo for shallow aquifer
Marango County-Coastal Plain	Upward flow of saline water within a fault	Well field moved to safer location	Unknown
ALASKA			
Yakutat area-Gulf of Alaska	Lateral intrusion from the ocean on a narrow sand spit when pumping from a 70-ft vertical well (Ghyben-Herzberg principle)	Installed shallow infiltration gallary to skim fresh water from the lens overlying sea water	Okay if demand does not exceed supply
Cook Inlet area-Anchorage	Potential of lateral intrusion from the ocean caused by intensive pumping	None	Present contamination at Fire Island; hazard to Anchorage well field; monitoring wells to be installed
ARIZONA	No known examples.		
ARKANSAS			
Various	Potential contamination from oil field brines leaking into fresh water aquifers	State requires casing or plugging of wells	Under control
Eastern	Lateral movement of saline water because of pumping	None	Unknown, depends upon all factors in hydrologic system; study proposed

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
Southern	Lateral salt water intrusion caused by updip migration resulting from pumping	None	Gradual local encroachment
CALIFORNIA Ventura County-Oxnard Plain	Lateral intrusion from ocean caused by intensive pumping	Experimental facilities in operation for control with a pumping trough by State Department of Water Resources and United Water Conservation District	Economic pressure will force solution;experimental work is continuing
Santa Clara County	Lateral intrusion from San Francisco Bay caused by intensive pumping	Pumping curtailed; recharging aquifer artificially	Managed groundwater basin
Los Angeles County-West Coast Basin	Lateral intrusion from ocean caused by intensive pumping	Intrusion stopped with a fresh water pressure barrier; pumping rates stabilized	Continued operation of barrier by Los Angeles County Flood Control District and management of the groundwater basin
COLORADO Denver Arsenal	Surface infiltration and lateral movement of industrial wastes caused contamination of adjacent aquifers	Industrial wastes moved to deep disposal well; well injection correlates with increased earthquake activity	Controversy
CONNECTICUT New Haven and Bridgeport	Lateral intrusion from tidewater in harbors caused by intensive pumping	Pumping relocated landward; alternate supplies used	Further pumping curtailment and greater use of alternate supplies

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
DELAWARE Coastline and Delaware River	Lateral intrusion from tidal water in Delaware River and Bay and from ocean caused by intensive pumping and dredging of impermeable soils	Pumping relocated landward	Continued intrusion; further pumping curtailment
FLORIDA Dade and Broward Counties-Miami	Infiltration of tidal water from canals constructed to drain inland areas and to lower water table	Canal construction controlled; installed canal salinity control structures to keep out sea water and to raise level of fresh water	Continued management of factors affecting water supply; continued surveillance and studies
Pinellas County-St. Petersburg	Lateral intrusion from ocean and Tampa Bay into thick limestone aquifers caused by intensive pumping	Pumping reduced	Investigation and management effort underway
Cocoa Beach-Cape Canaveral	Upward movement of residual salt water within thick limestone aquifer caused by intensive pumping	Pumping curtailment will be necessary. Replenishment by injecting surface water is being considered	Pumping limited to available supply
Hendry County-Southwest Florida	Localized upward movement of residual salt water into thick limestone aquifer caused by intensive pumping and broken or corroded well casings	Stopped pumping to the area	No change

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
GEORGIA			
Savannah area	Potential lateral intrusion from ocean into limestone aquifer resulting from massive cone of depression caused by intensive pumping	None yet because intrusion has not reached large production wells	Major pumping curtailment; continuing cooperative investigations
Brunswick	Wells encounter layers of residual salt water in thick limestone aquifers	None reported	Pumping from selected zones only; amount of pumping probably will have to be controlled; continued cooperative investigations
HAWAII			
Oahu	Potential lateral intrusion from ocean where pumping is too deep or excessive	Leaky wells controlled; pumping limited to amount of recharge, and locations chosen carefully	Continued management by Board of Water Supply; City and County of Honolulu; permanent operation of monitoring wells; continued studies to maximize safe production
IDAHO	No known examples		
ILLINOIS	Brine disposal	State control	
	Suspected lateral or upward movement of saline water		
INDIANA			
Various	Brine disposal	State control	Generally good
Mt. Vernon-West Franklin	Upward (?) flow of salinewater through fault zones into fresh-water aquifers owing to pumping	None	Bleak; abandonment of wells necessary

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
IOWA (?)	Potential updip migration of saline water within thick aquifers owing to intensive pumping	None	Localized problems only (?)
KANSAS Various	Brine disposal	State Board of Health controls	Controlled
Various	Potential infiltration of saline streamflow	None	Trouble;possible control of saline water sources
Various	Salt mine waste disposal	Disposal within mined out areas	Controlled
KENTUCKY	Discharge of oil field brines into streams and subsequent infiltration	State controls	Gradual improvement
LOUISIANA Baton Rouge	Lateral movement of residual saline water (or possibly industrial waste) into water supply well field owing to intensive pumping	None yet	Reduced pumping--supplementary water supply; continuing intensive studies
Vermilion River area	Lateral intrusion of tidal water from Vermilion River during low-flow periods into producing aquifer	Reduced pumping	River salinity control structure proposed
MAINE	No known examples		

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
MARYLAND Baltimore and Sparrow Point	Lateral and vertical intrusion from tidal estuary of Patapsco River into producing aquifers; problem was aggravated by harbor dredging, which improved exposure of permeable materials, and by leaky and broken well casings, which conducted saline water to deeper foundations	Little; reduction in pumping	Continuing intrusion; additional abandonment of wells; development of alternate supplies
MASSACHUSETTS Provincetown, Scituate and Somerset	Minor lateral intrusion from ocean and salt water marshes in shallow aquifers because of heavy pumping	None	Continuing local problem
MICHIGAN Various	Upward intrusion of saline water from deep bedrock into producing glacial aquifers owing to pumping; sometimes aggravated by heavy pumping and/or leaky or broken well casings	Reduced pumping and alternate water supply	Continued problem requiring adjusted pumping pattern or alternate water supply
MINNESOTA Northwest	Upward intrusion of saline water from deep bedrock into producing glacial aquifers caused by pumping	Reduced pumping	Use of alternate supplies
MISSISSIPPI Pascagoula area	Pascagoula Formation is subject to intrusion of salt water moving updip from the Gulf of Mexico	None	No problems yet; cooperative monitoring program underway

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
MISSOURI Various	Potential upward intrusion into producing aquifers from deep, saline aquifers, if pumping draft becomes too heavy		Good, because problem recognized
MONTANA Various	Brine disposal and leaky wells in saline formations	State laws	Trouble, compliance checks inadequate
NEBRASKA Northeast and East	Potential upward intrusion into producing aquifers from deep, saline aquifers	None	Not serious
NEVADA	No known examples; however, an inherent potential for lateral movement of saline groundwater		
NEW HAMPSHIRE Portsmouth	Minor lateral intrusion from tidal water in Piscataqua River	Unknown	Continuing problem
Various	Possible contamination by highway salt: This is a potential problem in many States, but apparently was not considered a salt water intrusion problem by most respondents		Alternate deicing methods when problem becomes serious; studies underway
NEW JERSEY Newark-Passaic River, Sayreville-Raritan River, Camden-Delaware River	Later intrusion from tidal estuaries into producing aquifers, aggravated by intensive pumping, harbor and canal dredging, and the disposal of industrial and municipal wastes	Pumping relocated; use of alternate supplies	Serious, until control measures established; studies are continuing

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
Atlantic City-Cape May	Lateral intrusion from ocean and Raritan and Delaware Bays owing to pumping	Pumping moved landward	Continued intrusion
NEW MEXICO			
Various	Upward intrusion into producing aquifers from deep, saline bedrock formations because of heavy pumping	Principally relocation of pumping wells	Grim
NEW YORK			
Long Island	Lateral intrusion from ocean into producing aquifers caused by heavy pumping and reduced natural recharge	Artificial recharge of storm runoff; reduced pumping; use of alternate supplies; Experiments with reclaimed water injection by USGS and Nassau County underway	Continuing intrusion; additional control measures and artificial recharge; intensive studies are continuing
NORTH CAROLINA			
Wilmington New Bern	Lateral intrusion from tidal estuaries into shallow producing aquifers owing to heavy pumping	Use of alternate supplies	Unknown
NORTH DAKOTA			
Red River Valley	Upward intrusion into producing aquifers from deep, saline bedrock formations due to pumping	None	Not good; studies underway
OHIO			
Muskingum River Basin	Industrial waste from chemical plants	Self-regulation by industry	Good
Various	Oil brine disposal	Regulation by State	Good
OKLAHOMA			
Various	Potential infiltration of oil field brines	State-controlled standards for deep disposal wells	Problems probably not increasing

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
OREGON	No known examples		
PENNSYLVANIA Philadelphia	Lateral intrusion of shallow aquifer by tidal water from Delaware River and by infiltration of industrial and municipal wastes, aggravated by heavy pumping and harbor dredging	Using alternate supplies	Continued intrusion until control measures instituted
RHODE ISLAND Providence Warren	Lateral intrusion of glacial outwash aquifers from tidal estuaries and ocean caused by pumping	Stopped pumping	Develop inland groundwater supplies; artificial recharge in coastal areas possible
SOUTH CAROLINA Paris Island	Heavy pumping in limestone aquifers causes upward and downward intrusion from layered saline aquifers	Pumping reduced	Limited pumping only
Beaufort area	Lateral intrusion from ocean into shallow, producing aquifer owing to pumping		
SOUTH DAKOTA Black Hills	Potential updip intrusion of saline water into producing aquifer because of increased pumping	None yet	Pumping curtailment may be necessary
Various	Localized upward intrusion into producing aquifers from deep, saline formations owing to pumping	None	
TENNESSEE	No known examples		

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
TEXAS			
Galveston-Texas City	Upward and/or downward intrusion of residual saline water into producing aquifers because of heavy pumping	Pumping moved inland; surface supplies developed; desalting being considered	Continuing problems
UTAH			
Great Salt Lake area	Potential lateral intrusion from lake into producing aquifers because of heavy pumping	None yet	May be serious
Western	Potential upward and/or lateral intrusion of saline waters into producing aquifers; also, an increase in salinity of ground-water from irrigation return flow	None	Conditions getting worse
VERMONT	No known examples		
VIRGINIA			
Newport News Cape Charles	Contaminated wells; could be intrusion of seawater or residual saline water	Unknown	Not known
WASHINGTON			
Tacoma area	Lateral intrusion from ocean owing to pumping	Wells moved inland	Continued intrusion
Grant County	Lateral intrusion into producing aquifer from vicinity of saline lakes because of pumping	None	
WEST VIRGINIA	No known examples; however, an inherent potential for movement of residual saline water		

TABLE 1.--CONTINUED

(1)	(2)	(3)	(4)
WISCONSIN			
Various	Lateral intrusion of saline water because of heavy pumping	None	Not generally serious
Various	Cannery waste disposal	State control	Serious, if control not effective
WYOMING			
Various	Mixing of fresh and saline water by intrusion through old oil wells	None	Localized problems
Various	Salinity increasing in groundwater because of irrigation return flow	None	Minor problems

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16. ABSTRACT

Salt water intrusion, from one or more sources outlined in this report, has resulted in degradation of subsurface fresh water aquifers in 43 States. Numerous case histories delineating current problems exist, providing adequate documentation of the seriousness of salt water intrusion.

Waste from municipal and industrial sources entering natural streams or reservoirs are responsible for the more visible types of pollution; their detection is rapid, their source can usually be identified, and their elimination will result in rapid natural improvement of water quality. In contrast, the clandestine movement of salt water through a fresh water aquifer continues, defying early detection, concealing its origin, and creating long-term problems with expensive remedies.

17. KEY WORDS AND DOCUMENT ANALYSIS

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