Earth Science Aspects in the Disposal of Inorganic Wastes

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ABSTRACT

In 1960 the management of International Salt Company made the decision that all waste material from the Watkins Glen Plant would be stored in underground salt cavities. The salt cavities which they contemplated using had been depleted of salt to a point where continued operation would have impaired their structural stability. Originally, the waste to be disposed of included vacuum pan bleeds, cinders, contaminated salt and sewage. The sewage was eliminated in favor of standard treatment facility and the cinders used. The effluent from the cavity was to be disposed of in the "black water" horizon called the Cherry Valley.

The Department of Environmental Conservation of the State of New York in 1971 "permitted" the disposal well which was to receive the effluent from the cavity. The project was activated immediately, thereby solving the Watkins Glen Plant waste problem. Currently, this is the only "permitted" deep disposal well in the State of New York.

HYDROGEOLOGICAL BACKGROUND

Watkins Glen is located within the northern periphery of the Appalachian Basin. Despite the proximity to the Canadian shield, there remains about 9,000 feet of Paleozoic sediments covering the metamorphic Precambrian basement. Stratigraphically the Paleozoic sediments are represented by the Cambrian, Ordovician, Silurian and Lower Devonian. With regard to lithology, the predominant types of sediments are shales, carbonates, evaporites and sandstones. These lithologic groups participate in the total Paleozoic sequence as follows:

Shales	57.5%
Carbonates	21.0%
Evaporites	8.5%
Sandstones	13.0%
	100.0%

Considering the lithological compositon, about 34% of the Paleozoic sediments in the Watkins Glen area can be recognized as actual or potential aquifers (sandstones and carbonates) approximately 57.5% as aquicludes (shales) and 8.5% as aquifuges (evaporites). The vertical distribution of individual lithological groups is diversified (Fig. 1).

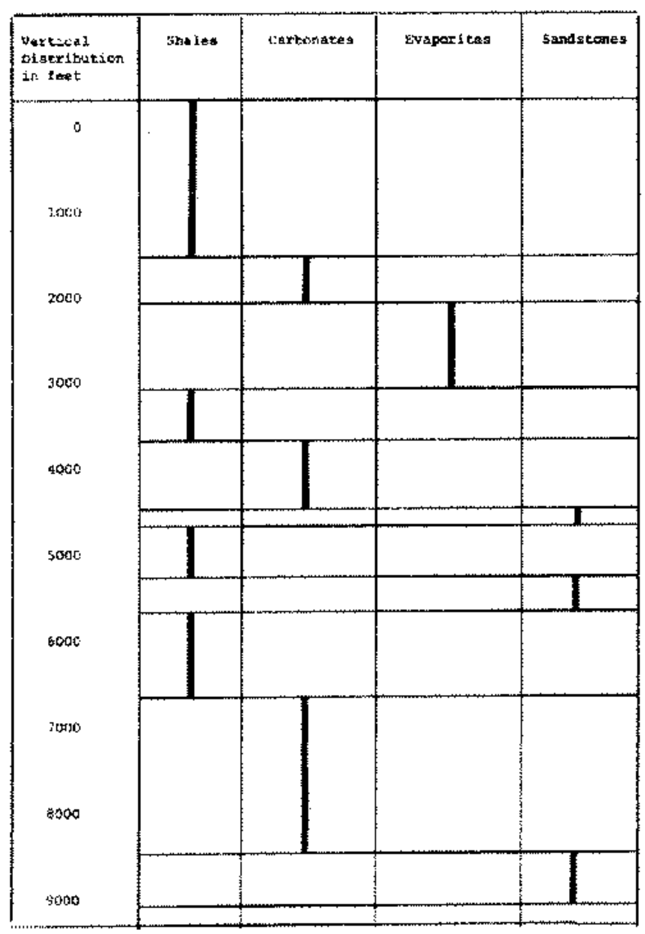

Figure 1. Vertical distribution of individual lithologic groups.

This correlation indicates that when looking for potential aquifers or fluid storage reservoirs at an economic depth, practical consideration dictates that only the carbonates overlying the Salina Group can be considered. In this area the sandstones below the 4,200' depth are known to be silty, well cemented, and compact with low effective porosity. It is known that hydraulic fracturing and chemical stimulation would be necessary for development of any storage capacity within these sandstones. Prospective disposal reservoirs within the sandstones are those of the Medina, Oswego and Potsdam, which are known to be depleted in some areas while still having potential reservoirs of hydrocarbons in other localities. A disposal operation into some of these horizons might be beneficial for extraction of the remaining reserves of natural gas. These horizons, from the standpoint of economic feasibility, exceed the economic levels acceptable for salt plant use. Only in the case of abandoned gas or oil wells, in the immediate plant site area, can this type of disposal be justified. The carbonates underlying the Salina sequence have hydrological characteristics which are worse than those of the upper carbonate sequences that overlie the salt. The major reason for this striking difference is tectonic.

Recent extensive studies of the tectonics of the area of Watkins Glen associated with our brining operations has led to a better understanding, not only of the geology of the salt, but also, the origin of the aquifers above the salt. It is known that individual cycles of the Appalachian orogeny, including those in the uppermost Paleozoic, exerted pressures on the sediments of the basin. These sediments were pushed towards the north, against the Canadian shield. The evaporites, located in the center of the sediments, being viscoplastic, absorbed most of the shock associated with the thrusting action and underwent extensive internal deformation. At the same time, the salt acted as a lubricant in between two rigid blocks of carbonates, one above, and the other below the Salina. Taking into consideration the weight of the overlying strata; the close proximity of the Canadian shield acting as a buffer, and a shock absorbing salt horizon above, the carbonates below the salt might have undergone extensive compaction as a result of any late Paleozoic movement. Conversely, the carbonate sequences above the salt were "floating" on the semi-plastic evaporites under a much smaller weight of overlying shales. These carbonates, broken in their structure, developed systems of internal fractures and fissures. These were the conditions for the development of a vast aquifer, known in New York state, as the black water horizon.

In the Watkins Glen area, this black water horizon became known as a fluid loss zone during the advent of the rotary drilling of salt wells in the 1950's. Formerly this horizon was considered to be limited to the Marcellus sequence. Recent observations indicate that depending on the vertical extent of the system of fractures, the black water horizon saturates the entire carbonate sequence, starting with the Cherry Valley limestone and extending downward to the Bertie dolomite. The "dry zone" at the bottom of the black water horizon is marked by the replacement of gypsum with anhydrite. This replacement phenomenon starts at the top of the Camillus shale, about 100 feet above the salt. The Hamilton shales and most probably the Upper Marcellus shales constitute the top, and the confining horizon for this aquifer. The hydrostatic pressure of the black water horizon in the plant area exceeds 500 psi. Its chemical composition is very complex and few, if any, accurate analyses of uncontaminated samples of this fluid are available. It is an undersaturated sodium, calcium, magnesium and potassium brine with abundant iron sulfates, gaseous hydrogen sulfide and even free ammonia.

The regional direction of dip of the "black water" is to the south-east. Transmissibilities are very diversified, and dependent on the system of fractures and fissures. The fissures are calcite lined and under induced flow conditions tend to widen with the dissolving action of the waste fluid, thus improving the transmissibilities of this horizon. There are no overlying ground water horizons above the "black water" except those within the terrace-delta's at the shore of the lake, moraines, and within the unconsolidated sediments on the lake bottom. These unconsolidated lake sediments extend to a depth of several hundreds of feet in the axial part of the lake, constituting a separate vast reservoir of ground waters. Since the shallow ground waters in the low terrace-delta area are often mineralized, it is certain that the waters within the deeper unconsolidated sediments of the lake valley are saline and of higher specific gravity than the fresh lake waters. The mineral/fresh water interface is somewhere below the bottom of the lake.

The above short outline of the hydrogeological background shows that the system of ground water conditions within the Watkins Glen area is complicated. It is multiboundary, in a three dimensional sense, is diversified hydrochemically and undergoes cyclic pulsations. It is hoped that further hydrogeological studies will be conducted and these will lead to a better understanding of this subject.

THE DISPOSAL SYSTEM

The subsurface disposal facilities developed by the International Salt Company at Watkins Glen, New York have operated since November 3, 1971. The waste material from the plant consists of vacuum pan bleeds, sludges from the purification of raw brine, and contaminated salt. The main chemical components of this waste are, calcium and magnesium carbonates; calcium, magnesium and sodium sulfates and magnesium hydroxide. In other

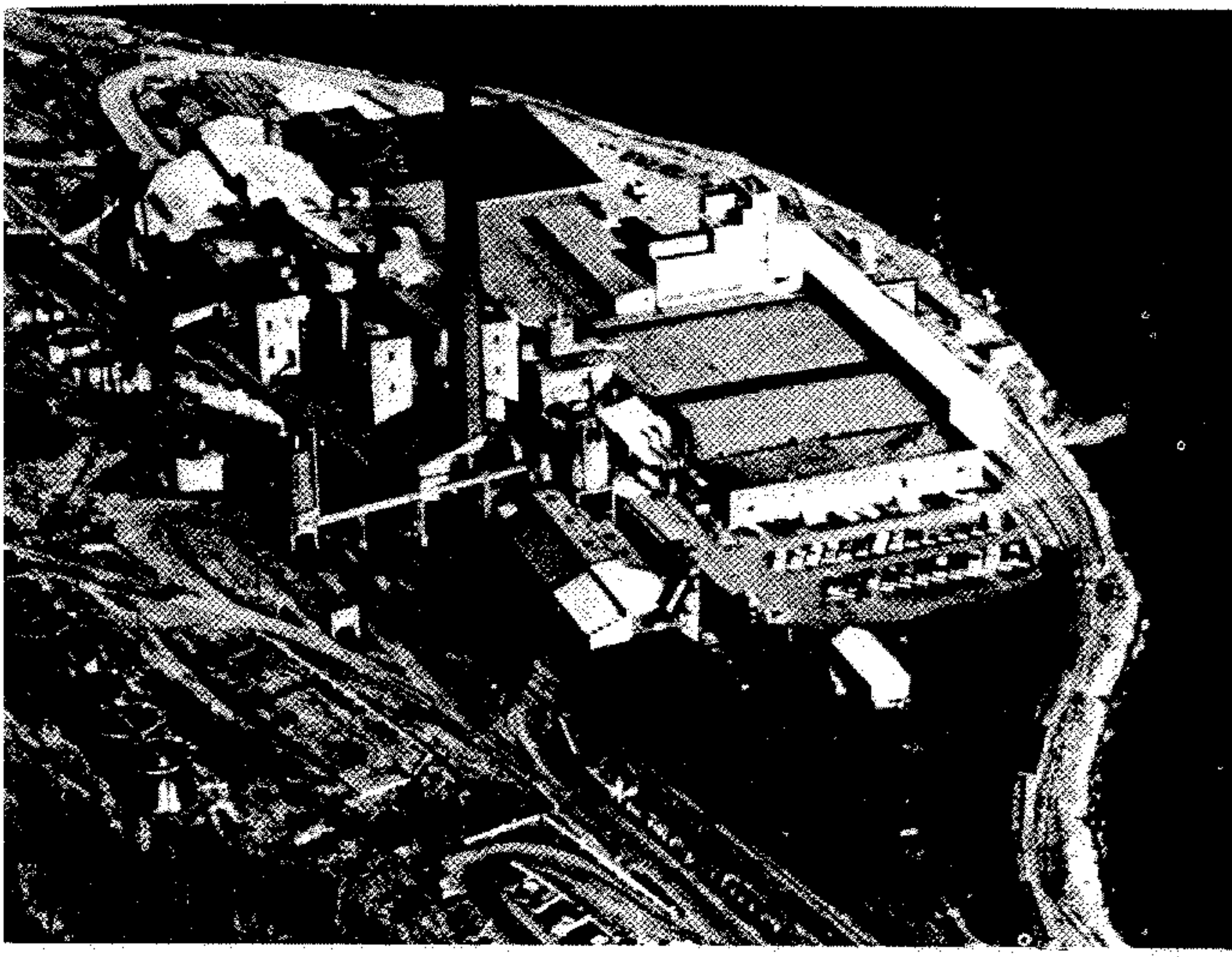

Figure 2. Aerial view of the Watkins Glen plant showing discolored waters of the lake.

words, these wastes are predominantly natural, inorganic, mineral components associated with the halite deposit that are residual after extraction of sodium chloride, the product. Before the subsurface disposal operation started, an average of about 80,000 gallons/day of the effluent were disposed into the waters of the Seneca Lake, near the shore on which the plant is located. To find an environmentally appropriate solution for disposal of these industrial wastes was extremely important, in view of the fact that the Seneca Lake area has an established reputation as a prominent tourist attraction within the Finger Lakes area, famous for boating, fishing and water skiing. A picture from a few years ago with an aerial view of the salt plant shows distinctly the discolored waters of the lake, at the outflow area of the plant effluent (Fig. 2). A recent picture of the same area after the subsurface disposal operation started is shown in Figure 3.

The disposal system consists of three reconditioned salt wells, a system of abandoned salt cavities and surface conditioning reservoirs (Fig. 4). The cavities were created

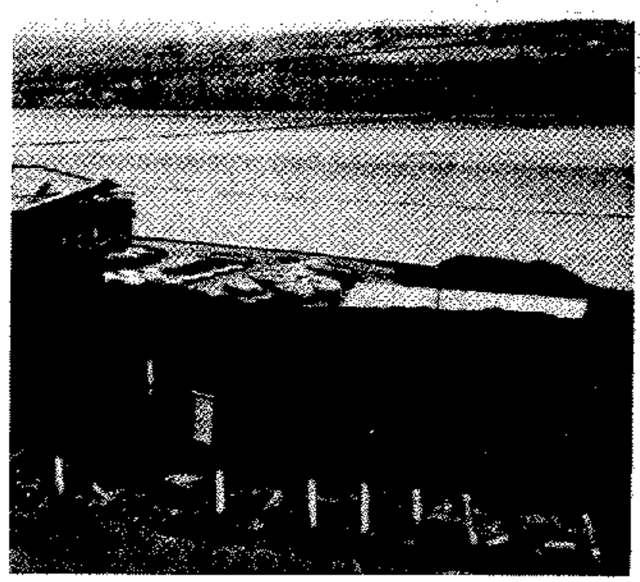

Figure 3. A recent photograph of the Watkins Glen plant after the subsurface disposal operation started.

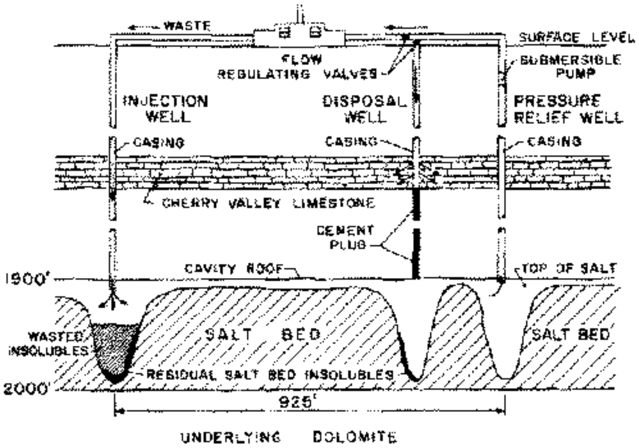

Figure 4. Disposal system of three reconditioned salt wells, salt caverns, and surface reconditioning reservoirs.

as single wells with annual water injection in the upper 90 feet of the first salt bed. During normal operations of these wells, "morning glory" shaped cavities were formed with the wells being interconnected along the top of the salt. These interconnected wells created broad roof spans which were considered as a possible potential subsidence hazzard to the overlying plant and thus the cavities were abandoned in "early maturity." Once brining operations in these cavities ceased, the small amount of rock movement which had been previously recorded was substantially reduced. It is expected that the greatest cavity height in this type of cavity occurs at the bore of the well. Dense, waste deltas initially fill that portion of the cavity adjacent to the well bore and subsequently flowing out into the long radial links of the cavity.

The cavity fluid, displaced by the injection of the heavier waste material, is expelled from the cavity through the pressure relief well. This well is equipped with a submersible pump which lifts the brine and injects it underground into the black water horizon, specifically into the open hole sequence at the Cherry Valley limestone. Alternatively, this fluid can be reinjected into the evaporator system when the salinity, chemical composition and mechanically suspended solids are of such a condition and nature as to formulate a satisfactory feed brine.

Under the laws of the State of New York only the disposal well portion of this system was subject to a permit. Three limiting factors are incorporated in the operational permit in respect to the disposal well. These are as follows:

(a) The wellhead pressure should not exceed 300 psi.
(b) The annual pressure should not exceed 50 psi.
(c) The rate of injection should not exceed 160 gpm.

All these parameters, plus specific conductance of the injection fluid are continuously recorded. Ground waters around the injection well are periodically sampled and analyzed, and the operational data is reported periodically to the Department of Conservation of the State of New York.

The limit of wellhead pressure, as stipulated in the government permit, was developed on the basis of data extrapolated from a 24 hour pump test of the injection horizon. A drawdown test showed a specific yield of 0.25 gpm/foot of head in excess of the static head where the fluid was of the same specific gravity as that of the formation.

Any limiting wellhead pressure calculated on a basis of this specific intake capacity was considered to be conservatively high since the salinity of the fluid on the top portion of the abandoned cavity was considered to be initially undersaturated. The specific gravity of the cavity effluent was expected to gradually increase. Subsequently the estimate has proven to be correct. The injection operation into the brine disposal well started with 215 psi of wellhead pressure at 160 gpm and within the first four months of operation the intake capacity of the well has improved and the wellhead pressure decreased (Fig. 5). The anticipated increase in salinity is shown in Figure 6.

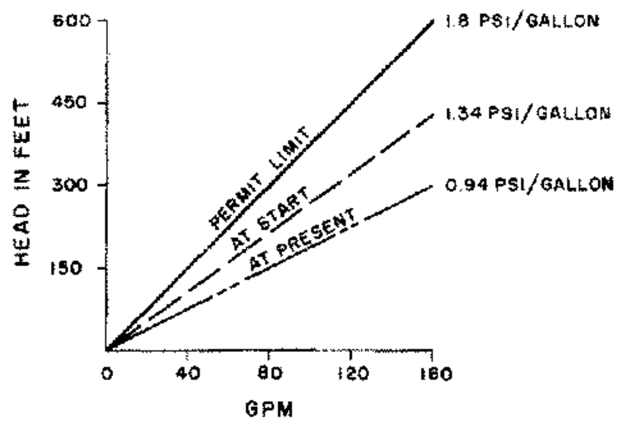

Figure 5. Injection well head pressure.

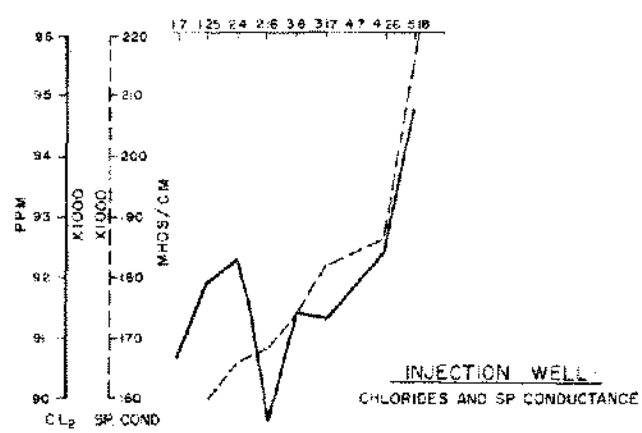

Figure 6. Increase in salinity at injection well.

The improvement in the intake capacity of the well is attributed to the nature of the flow of fluids in the limestone i.e. the flow of fluid through a system of heterogeneous fissures and voids with the possible concurrent dissolving of calcite.

The chemical composition of shallow ground waters around the injection well is monitored by five observation wells. Location of these wells is shown in Figure 7. Samples of water from these wells are taken after an hour of pumping. The specific conductance and pH is determined in the field immediately after the sample is taken. The analyses for chlorides and sulfides are made in the plant laboratory.

The concentration of ions in the ground water is a function of yearly and multi-yearly cyclic changes within the ground water horizon. Perhaps the most important single facet of this type of operation is the establishment of a historical background of environmental data prior to commencement of operation. Under normal conditions high static ground water levels are associated with low concentrations of ions while high ion concentrations are characteristic of low ground water levels (Fig. 8).

STABILITY CONSIDERATIONS IN CAVITIES FOR WASTE DISPOSALS

The stability of salt cavities is still a matter of considerable controversy and debate, but it is almost universally accepted that the size and shape of the cavity changes with time. In the method of solution mining, the point of injection and withdrawal of brine, the rate of solution and fluid circulation in the cavity are the factors used by the operator to design a cavity. Geological factors also effect the shape, size and stability of the cavity.

To select a cavity for waste disposal, one should look at the depth, roof span, shape of the cavity and kind of roof rock which overlies the excavation. The stability of the ground above the cavity depends on the theoretical intensification of stress over the top of the cavity. These stresses may either stabilize the rock giving rise to arching, or they may cause rock fracturing which will lead to a relief of the stress. Furthermore, individual strata may tend to sag, giving rise to compressive or tensile stress depending on the neutral axis of the sagging plates.

In the case of a wide cavity with "morning glory" shape, overlying incompetent rock, roof falls occur in various places depending upon various circumstances. The initial falls are likely to be smaller in size and flat bottom in shape. After the first fall the roof may fail a second, third or fourth time, assuming a dome-like configuration. If the fall progresses to a competent rock formation, the angle of the dome is likely to steepen and after minor spallings over a long period of time, the roof is likely to stabilize. On the other hand, if the approaching dome shape configuration leads to an incompetent rock formation, especially one with water or unconsolidated strata, the dome will tend to reach the surface resulting in a sink hole of some form.

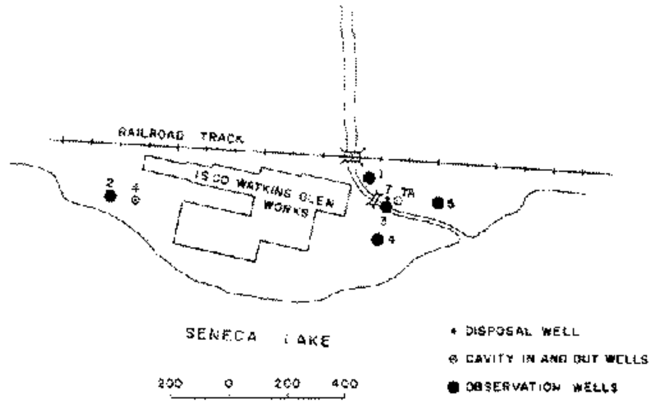

Figure 7. Location of disposal and observation wells at Watkins Glen plant.

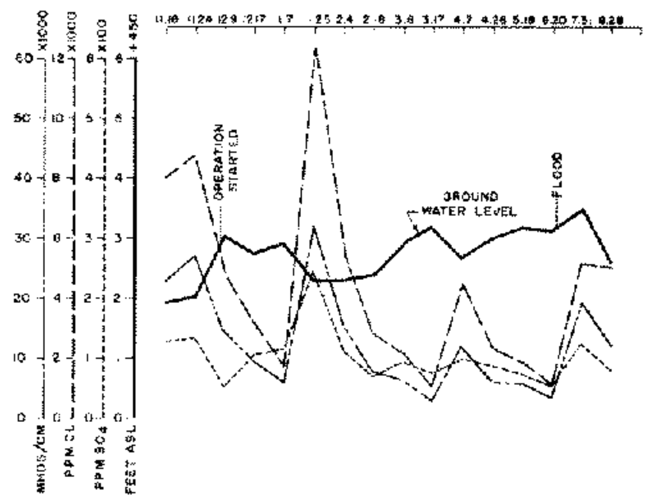

Figure 8. Ground water levels determined from observation well No. 1.

FINAL REMARKS

1. The acceptance of cavity brines by the "black water" horizon proved to be better than anticipated. The disposal well is operating under pressures well below the permitted pressures. The salinity of brine injected into the cavity must be 100% in order to avoid the dissolving of any additional salt from the salt beds.

2. The disposal operation has not had any adverse affect on the environment. Specifically, the shallow ground waters in the surrounding area show no evidence of change.

3. To maintain a stable cavity for waste disposal it is necessary to maintain sufficient hydrostatic pressure in the cavity to enable support of the roof. The injection fluid has to be thoroughly saturated with salt so that no further

dissolution of salt takes place, preferably a bottom injection of the fluidized waste is suggested from a rock mechanics point of view.

4. It is advisable to choose a cavity which is hydrostatically "tight," which is preferably deep-seated and of a "non-morning glory" type shape.

5. It is mandatory that sufficient background data on the hydrogeological aspects of the area be established prior to commencement of disposal operation so that the cyclic variations in ground water flows and their chemical composition can be established.