

## XIV. UNDERGROUND GAS STORAGE

### A. INTRODUCTION

The storage of natural gas in underground facilities in New York State is done to meet the cyclic demand for energy by the consumer while providing a continuous market for produced gas. Gas is injected into the storage reservoir during the warmer months when consumer demand is low and it is withdrawn during the peak winter heating season to supplement the existing supply. Figure 14.1 details consumer energy demand on a seasonal basis. Natural gas can be stored in depleted gas reservoirs, aquifers, depleted oil reservoirs, and solution mined salt caverns. Liquefied Petroleum Gas (LPG) is stored by producers to meet fluctuating or variable demand while distributors use storage facilities to supply customers with a constant supply. Large-scale consumers of LPG benefit from bulk storage by ensuring themselves of a constant supply during times of shortage. LPG is stored in solution mined salt cavities, conventionally mined caverns in impervious rock, and confined porous reservoirs.

Presently in New York State there are 21 natural gas storage and three LPG storage facilities in operation as shown in Figure 14.2. All of the natural gas storage fields utilize depleted gas reservoirs most commonly found in the Medina and Oriskany sandstones. The oldest natural gas storage facility is the Zoar Field in Erie county which was started in 1916 (Van Tyne and Foster, 1980). Depleted gas fields are the popular choice for storage projects because the reservoir properties that were favorable for production are also favorable for storage. They are in close proximity to existing transportation facilities and most old reservoirs offer a large potential storage volume. Of the three existing LPG storage facilities, two are in abandoned salt cavities. The third and newest project utilizes a mined storage cavern. The following sections detail the underground storage of

FIGURE 14.1 NATURAL GAS SUPPLY AND DEMAND CURVE

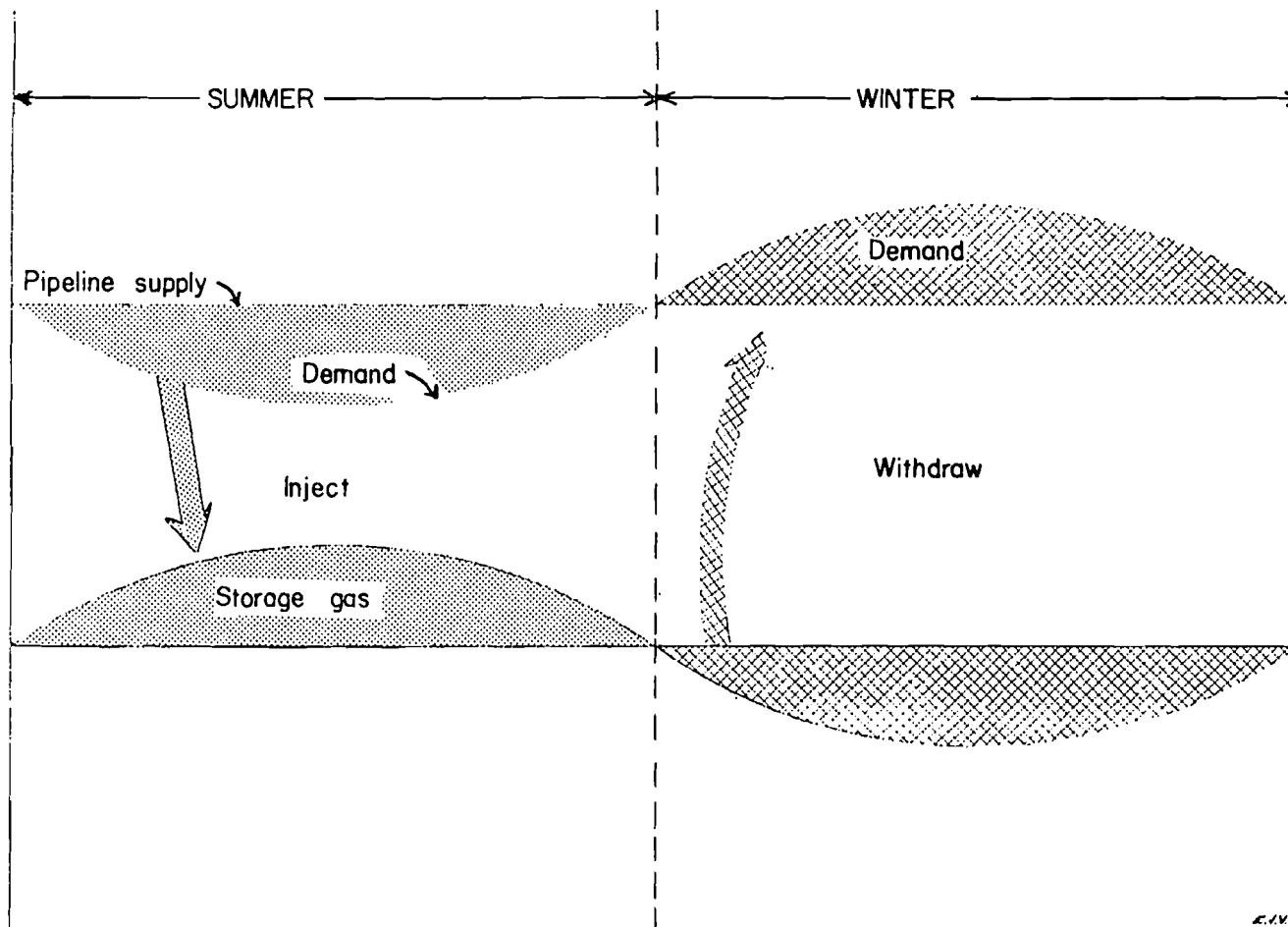


FIGURE 14.1  
14-1a

FIGURE 14.2

LOCATION MAP  
NEW YORK STATE  
UNDERGROUND STORAGE  
RESERVOIRS

○ - NATURAL GAS STOR.

△ - LPG STORAGE

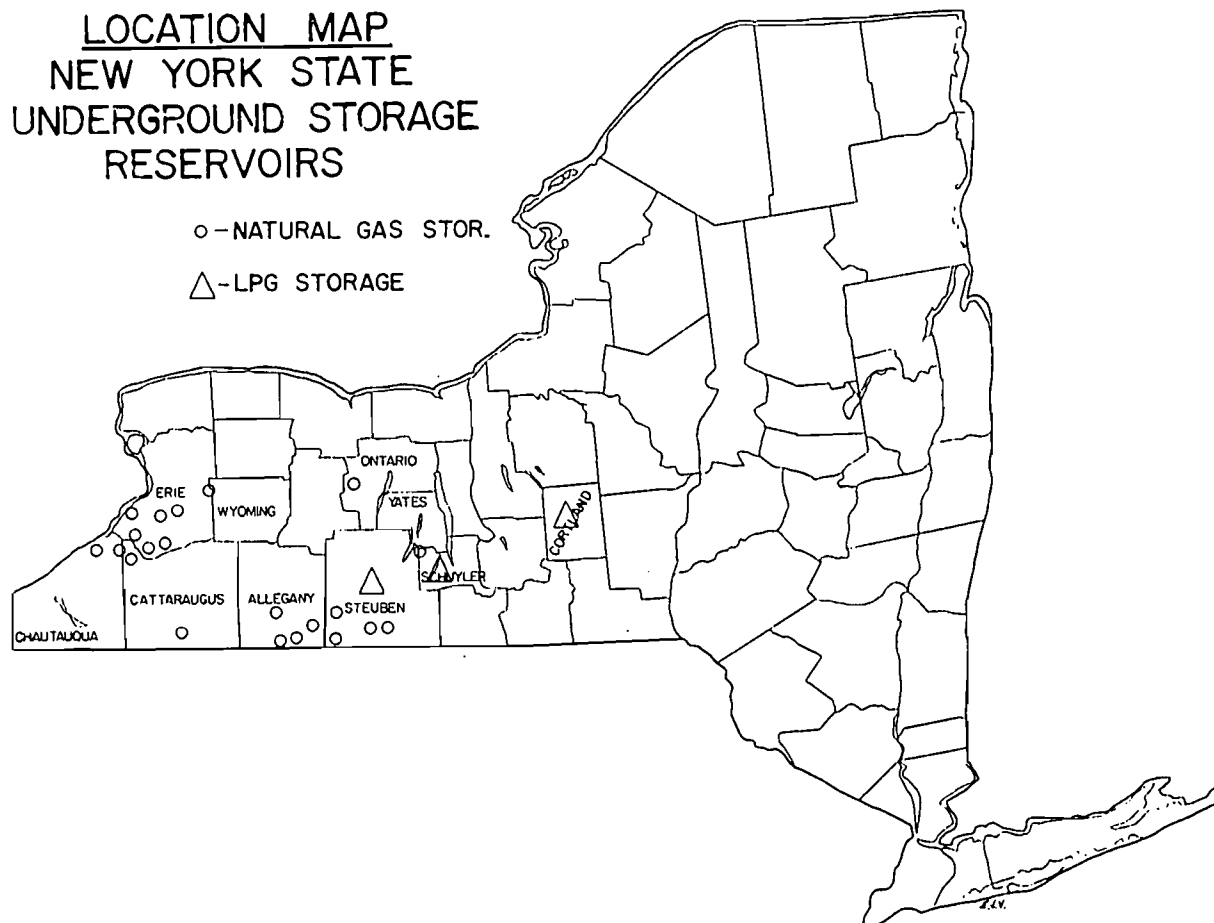


FIGURE 14.2

14-1b

natural gas and LPG as it pertains to the environment in terms of the existing and proposed State Regulatory Program.

## B. STORAGE SITE SELECTION AND FORMATION EVALUATION

### 1. Depleted Gas Reservoirs

As mentioned previously, all 21 natural gas storage facilities in New York State utilize depleted or partially depleted gas reservoirs. A typical gas storage reservoir is shown in Figure 14.3. Site location is dictated by the existing reservoir location. This usually affords the operator access to transportation facilities as well as any operational or idle wells. The feasibility of the proposed storage site is evaluated using data obtained from previous operations. This data includes gas reservoir volume, initial and current reservoir pressure, aquifer influence, potential operational pressure, and expected gas deliverability.

The geology of the proposed storage area is studied carefully to assess the feasibility of controlled gas storage and withdrawal. The gas reservoir limits are defined including the reservoir boundaries and the trapping mechanism which allowed original gas accumulation. Because of the high cost of initiating a storage project, only larger capacity fields with above average porosity and permeability are considered (Van Tyne and Foster, 1980). For example, Oriskany sandstone reservoirs are well suited for storage because they can be operated at high pressures which allows larger gas input into a fixed volume. They may be drained by fewer wells and have relatively well defined boundaries.

The preliminary testing program for proposed storage in a depleted gas reservoir usually consists of obtaining well head pressures from existing wells. This aids in discerning the reservoir limits as well as defining the current reservoir pressure. Normally, no new wells are drilled during this

FIGURE 14.3 CROSS SECTION OF A NATURAL GAS STORAGE RESERVOIR

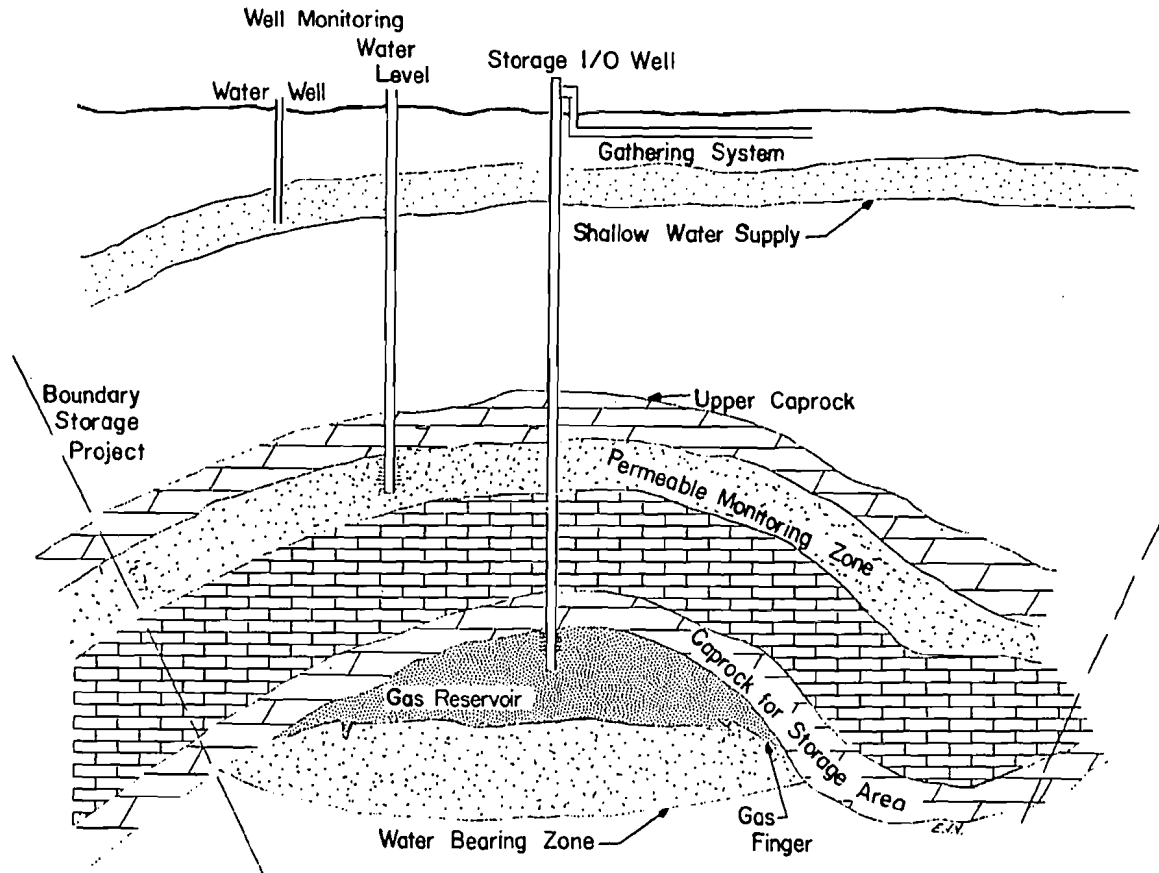


FIGURE 14.3

phase.

## 2. Solution Mined Salt Cavities

Two of the three current LPG storage facilities in New York State are in salt cavities created by solution mining operations. The salt is contained in beds which results in an irregular cavity shape as shown in Figure 14.4. See the chapter on solution mining operations for a discussion of this process including the State's Regulatory Program. Site selection of a proposed storage facility depends upon the salt cavity location. Some flexibility does exist as the operator may create a salt cavern in a more desirable location, but the additional expense can be prohibitive.

The salt cavity must be at a depth sufficient enough to balance the vapor pressure of the product being stored (Marks, 1983). This ensures safe operation of the cavity at maximum pressures without the danger of leaks and gas migration out of the structure.

Since the data obtained from previous operations is sufficient for evaluation of the storage cavity, no new wells are drilled during this phase.

## 3. Conventionally Mined Storage Caverns

The newest LPG storage project in New York State is the mined storage cavern at Watkins Glen operated by Texas Eastern Products Pipeline Company. This facility became operational in 1984. Since the ideal cavern storage rock is an impervious granite, shale, or a deep salt bed with no permeability, a storage site is chosen based on the existence of these formations. Figure 14.5 is a cross-section of typical mined storage cavern. Specifically, the potential cavern formation must be at a sufficient depth to control the vapor pressure of the stored substance, it must be areally extensive so as to allow storage of commercial quantities of product, and it must be almost homogeneous with no secondary permeability or communicating fractures (Marks, 1983).

In order to adequately assess the potential storage rock, test wells are

FIGURE 14.4 CROSS SECTION OF A SALT CAVITY

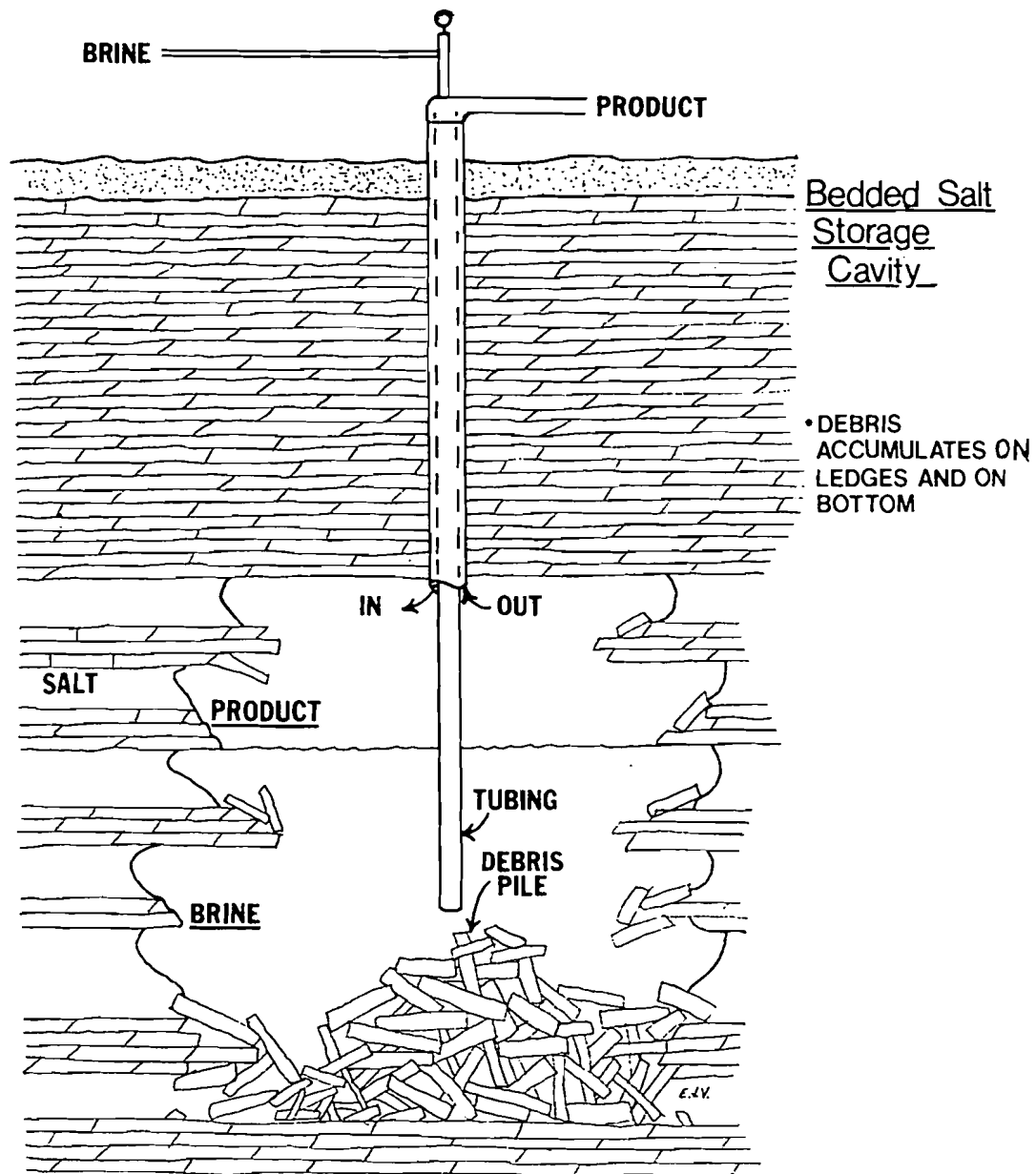


FIGURE 14.4

14-3a

FIGURE 14.5 CROSS SECTION OF A MINED STORAGE CAVERN

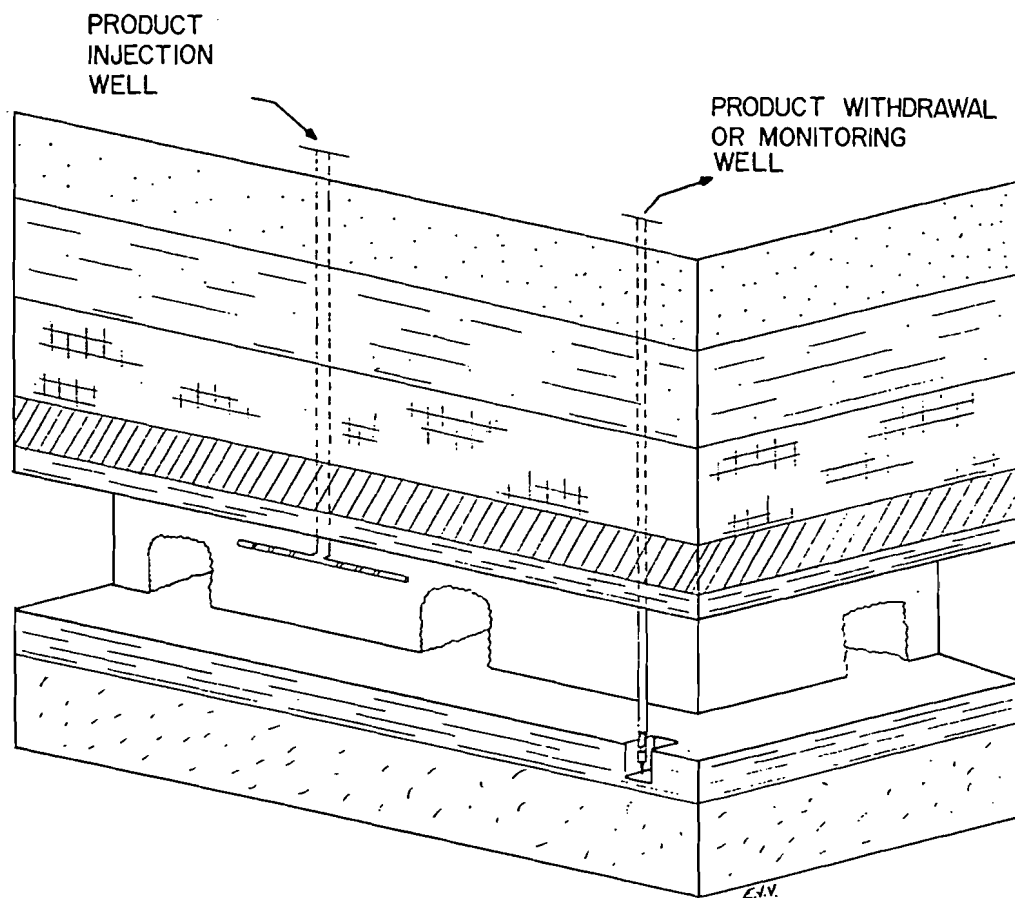


FIGURE 14.5

14-3b



drilled and conventional core samples are recovered from the storage rock and the surrounding formation. If the cavern proves favorable for storage, these wells will either be converted for injection/withdrawal or pressure monitoring or they will be plugged and abandoned. Current State regulations require that a permit must be obtained from the Department of Environmental Conservation before a well can be drilled, deepened, plugged back, or converted for the purpose of oil and gas production, input, storage or disposal [6NYCRR Part 552.2].

Since there are currently no State laws or regulations governing the drilling and abandonment practices associated with test wells, it is suggested that the new regulatory program contain provisions for including this type of well in the permitting process. A test well category will be added to the existing DEC permit application form to coincide with the new test well regulations. Proposed test well drilling would then fall under the DEC review process which would ensure that the State's approved drilling and abandonment practices are followed. See the section of the text entitled, New York State's Oil, Gas and Solution Mining Regulatory Program for more details concerning the permit application, permit fees, financial security, and the DEC review process.

The formation sample obtained during the coring process is then tested to determine its storage feasibility. Data are reviewed and correlated from several test wells. The testing program usually consists of the following:

- a. Immersion tests - core material from the proposed storage formation is submerged in a sample of the gas or LPG storage product as well as a sample of water. After five days, the core material is inspected for any deterioration. If some breakdown or change in the core rock is observed, the formation would not be recommended for

storage.

- b. Rock Quality Designation (RQD) - This method is used to determine the overall integrity of the formation. Core recovery is the amount of cored rock that is physically recovered from the formation as a percentage of the interval that was actually cored. RQD is a modified core recovery percentage in which only those pieces of solid, unfractured core over four inches long are counted as recovery. Zones of core loss, highly weathered sections, and short pieces caused by shearing, jointing, or faulting are not counted because they reflect adverse rock properties.
- c. Visual inspection of the core material for secondary permeability such as interconnected natural fractures.
- d. Determination of the rock's horizontal permeability to the stored substance, it's effective porosity, and it's unconfined compressive strength.
- e. Injection Testing - usually done to evaluate fractures in the formation rock. The test consists of observing the water lost to the formation from a static water column in the test well bore.

The next step in the site formation evaluation process for all types of storage situations involves assessing the earthquake potential of the proposed storage area. Damage to cemented casing, tubing and wellhead equipment caused by ground motion could lead to potentially dangerous gas leakage. A large enough earthquake could conceivably cause enough damage to an underground storage cavern to place offset mining operations in jeopardy. If migration should occur, there is a danger of miner asphyxiation, mine explosions, or escape of gas into the atmosphere. The following section dealing with storage permit procedures will address offset operations and their implications in more detail.

Fortunately, earthquakes severe enough to cause damage are very rare in New York State. **Nevertheless, it is suggested that operators be required to address the potential earthquake dangers associated with their particular storage situation in the environmental assessment made prior to approval of a new storage field.** This should include a review of earthquake incidences in the storage area noting any surface or sub-surface damage. The potential earthquake risk and potential dangers should be detailed along with mitigation plans.

An underground storage feasibility report is usually prepared at this stage which summarizes the findings obtained during the testing and evaluation of the proposed storage project. This report is then submitted to the DEC in order to start the permitting process for the storage facility.

#### C. APPLYING FOR AN UNDERGROUND STORAGE PERMIT

Significant amendments were made to the Oil, Gas and Solution Mining Laws in 1981 concerning the underground storage of gas. The new regulations will reflect these changes to the law. The procedures for obtaining an underground storage permit state that no underground reservoir shall be devoted to the storage of gas, or liquefied petroleum gas unless the prospective operator of such storage reservoir shall have received from the Department, after approval in writing of the State Geologist, an underground storage permit which shall be in full force [ECL 23-1301.1]. The permit application is required to include the following:

1. A map showing the location and boundaries of the proposed underground storage reservoir.
2. A report containing sufficient data to show that the reservoir is adaptable for storage purposes.
3. An affidavit signed by the operator to the effect that he has

acquired by grant, lease or other agreement at least 75 percent of the storage rights in said reservoir and in the buffer zone established to protect the reservoir as approved by the Department, calculated on the basis of surface acreage; and such affidavit shall also set forth that the applicant will agree as a condition to the issuance of such permit that it will thereafter within a reasonable time either acquire by negotiation, or file and proceed with condemnation proceedings to acquire, any outstanding storage rights in the remaining reservoir and buffer zone acreage.

4. Such other information as the Department may require.

The operator will have previously filed an application with the Federal Energy Regulatory Commission for a certificate of public convenience and necessity pursuant to Section 7(c) of the Natural Gas Act. This certificate authorizes the operator to construct and operate certain facilities for the storage of natural gas or LPG. A site specific EIS is also submitted to FERC at this time. More information on federal regulation of gas storage projects can be found in the appendix. State law requires that buffer zone acreage be acquired along with that needed for storage purposes because the exact limits of any reservoir cannot be precisely defined. Therefore, a transition zone is needed to protect the reservoir from offset operators and vice-versa. The Oil, Gas and Solution Mining Law has been amended to state that the buffer zone is that area outside and surrounding the underground gas storage reservoir which the Department approves as appropriate to protect the integrity of the reservoir, no part of which shall be more than 3,500 linear feet from the boundary thereof [ECL 23-0101.1]. The new regulations will incorporate this amendment.

The boundaries of a gas storage reservoir are estimated using volumetric calculations, subsurface geologic studies, and by correlating wellhead

pressures from wells throughout the field. Since the approximate storage pressure of the reservoir is known from gas production histories, pressures at wells significantly below that level would indicate the outer limits of the reservoir. The buffer zone regulation for a gas storage reservoir is similar to a spacing order for an oil and gas well. By identifying and leasing storage rights to a buffer zone, the operator has some protection from gas operations on offsetting leases. Some gas storage reservoirs are in blanket sands such as the Medina which are relatively continuous with little structural control. Offset gas operations could conceivably deplete a storage reservoir in such a sand very easily if no buffer zone were required.

The buffer zone requirement does not have quite the same application to storage in abandoned salt cavities or mined caverns. Wells offsetting a salt cavity or a mined cavern would not be completed in the storage formation due to lack of virgin gas in a salt bed or an impervious shale or granite. There are, however, some dangers associated with offset underground mining operations. Underground blasting may cause fractures in the storage cavern or cap rock allowing gas leakage to the surface, water table, or into the mine creating a dangerous, toxic situation. The DEC requires that operators give notice to persons engaged in underground mining operations of the commencement of any phase of oil or gas well operations which may affect the safety of such underground mining operations [ECL 23-0305.8(j)]. Due to the site specific nature of storage operations, the distance from underground mining operations within which notification will be required will be established via permit conditions. This requirement will apply to all operations associated with underground storage in abandoned salt cavities and mined caverns.

The November 1981, Oil, Gas and Solution Mining Legislation specifies

requirements and procedures for acquiring storage leases. As mentioned previously, the operator must submit an affidavit when applying for a storage permit that attests to the acquisition of at least 75 percent of the storage rights in the reservoir and buffer zone. This requirement ensures safe, efficient operation of the storage facility. The operator then has up to two years after the first injection of gas to secure the remaining twenty-five percent storage rights [ECL 23-1303.3].

This seventy-five/twenty-five percent acquisition law was structured as such by the State so that storage facilities could be brought on line relatively fast in times of projected gas supply shortages. By needing only seventy-five percent of the storage rights initially, the operator is not delayed by lease acquisitions and can therefore concentrate on bringing the facility on stream. If the remaining twenty-five percent storage rights necessary for activation, operation, or protection of the storage reservoir and its buffer zone cannot be acquired after reasonable effort within the aforementioned two year period, the operator has the power to secure such rights under the applicable provisions of the eminent domain procedure law [ECL 23-1301.1]. Before filing a suit for acquisition proceedings, the operator is required to file a map with the Department detailing the location, boundaries, and surface acreage of the reservoir and buffer zone [ECL 23-1303.2].

The powers of eminent domain are granted in the case of underground storage so that the needs of the State's energy consumers can be met. When shortages arise due to excessive energy demand during the winter heating season, the ability to augment supplies of natural gas or LPG from underground storage facilities is vital to the State. These laws ensure that a storage facility deemed structurally and operationally safe by the Department will be installed without delay so as to better serve the public.

Prior to enacting acquisition proceedings against landowners, every attempt is made to lease storage rights by negotiation or voluntary agreement. The Department may grant extensions to the two year lease requirement for additional negotiations, if necessary. In addition to the storage value of any property being leased, the value of any commercially recoverable native oil and gas in place must also be considered [ECL 23-1303.5]. This provision also holds true for salt rights.

The Department's underground storage permit application review process is initiated upon receiving the previously discussed maps, reports, affidavit, and other data from the proposed storage project operator. An application fee of ten thousand dollars for a new underground storage project or five thousand dollars for a modification of an existing storage facility is required with the permit application [ECL 23-1301.5(a)(b)]. A modification to an existing storage project would be an expansion of the boundaries of the storage reservoir or an increase in the maximum storage pressure. **It is suggested that this definition of a storage project modification be specified in regulation.**

As detailed previously, the Oil, Gas and Solution Mining Law requires the operator to submit a map, a reservoir report, a leasing affidavit, and any other project specific information. This technical data is used by the Department to assess the feasibility and environmental compatability of the proposed storage project.

**It is suggested that the new regulations specify that the following information be submitted when applying for a storage permit:**

- 1. Project location information including the county and town, the field or pool name, and a map detailing the boundaries of the reservoir and buffer zone.**

2. A geologic description of the reservoir. This should include the type of formation, its porosity and permeability, the geologic trap, and the original saturations.
3. The controlling factors on the lateral extent of the reservoir.
4. A brief history of the development of the reservoir. This should include estimates of the original gas in place, historic production, and remaining native gas.
5. The original reservoir pressure of the reservoir and the expected maximum operating storage pressure.
6. Estimates of cushion gas and working gas volumes and expected well and field deliverabilities.
7. Compressor Requirements - the number of compressors needed, their total horsepower, and a location map.
8. Other data that may be required by the Department

The technical information submitted should also contain well status reports and the lease acquisition affidavit attesting to the operator having secured storage rights for at least seventy-five percent of the reservoir and buffer zone. As mentioned previously, the technical information is reviewed by the State Geologist who then submits to the Department his/her approval in writing. Offsetting oil and gas activity is also reviewed at this time in order to assess the storage project's impact on offsetting operations or vice versa. A copy of the EIS submitted to FERC will also be required when applying for a state storage permit. A major modification to an existing project will require a SEQR determination and a supplemental EIS may have to be prepared.

A precise well status report is presently not required by the Department but some type of well information is usually solicited from the operator during the review period. As part of the new permit application process, a



**detailed well review will be required. The following information should be contained in the well report:**

1. All wells (including API number and operator) within the reservoir, buffer zone, and surrounding acreage as deemed appropriate by the Department. A map showing these locations should also be submitted.
2. A breakdown of the wells by operational status such as active, idled, or abandoned.
3. A detailed history of each well including the condition of casing and tubulars, the well's workover record, and all well logs.
4. Wellhead pressure history for all wells.
5. The planned disposition of any test wells drilled for the purpose of evaluating the project's feasibility. A permit must be obtained from the Department for conversion of any oil and gas well [6 NYCRR Part 552.2].
6. Any other information as required.

In the case of storage in depleted reservoirs, the competency of the formation and its structure are usually well known. However, such fields are likely to have many wells drilled either to or through the reservoir under consideration and the field may also be bordered by several abandoned wells. An up-to-date, complete well assessment record is essential for the Department to determine the operational feasibility of the proposed storage project. Improperly abandoned wells or wells with corroded or collapsed casing could allow gas migration to the water table or the surface. Corroded casings may need to be lined or permanently plugged. Incorrectly abandoned wells should be reopened and properly cemented. The State must obtain positive assurance that all wells are or can be made mechanically tight.

The underground storage permit shall be granted within ninety days of

application unless the Department finds that the application and the information submitted with it do not meet the aforementioned requirements. The Department may revoke or suspend any storage permit for failure to comply with any of its provisions [ECL 23-1301.2]. The laws and the proposed regulations as previously discussed concerning permitting, shall not apply to underground storage projects placed in operation prior to October 1, 1963 and so long as such operation is not abandoned [ECL 23-1301.3]. No permit issued by the Department shall be construed to diminish or impair the jurisdiction of the Public Service Commission with respect to regulation of the manufacture, transportation, distribution or sale of gas [ECL 23-1301.3].

The Department also requires that every operator file an annual report detailing the status of the storage project. This report should highlight any change in the size or shape of the reservoir and buffer zone (in terms of surface acreage), the total capacity and working capacity of the reservoir, and any other engineering, geological, or operational data that may be requested by the Department [ECL 23-1301.4]. This last item will include updates to the data presented in the technical information section of the proposed permit application form. The yearly operations reports are reviewed and compared with previous years' data in order to assess the efficiency, operational stability, and environmental soundness of the storage project.

The main concerns of the Department are the controlled confinement and the safe injection and withdrawal of the natural gas or LPG. Over-injection of product could cause erratic increases in the reservoir or buffer zone boundaries while a sudden decrease in the reservoir storage pressure would most likely be due to a leak of some kind. Both situations would require immediate action to protect the environment as well as the safety and the rights of offset landowners.

#### D. CONSTRUCTION OF THE STORAGE SITE AND ACCESS ROADS

The size of underground gas storage reservoirs in New York State ranges from 280 acres to 10,800 acres but the surface area disturbed during site construction rarely exceeds 80 acres. Most of the disturbed acreage is located in a central area where the compressors and distribution system are situated along with one or more injection/withdrawal wells. Access roads and the remaining well sites make up the balance of the overall storage site.

For underground storage in depleted gas reservoirs or abandoned salt cavities, the majority of the well sites and access roads are already in place due to previous operations. The siting and construction requirements for access roads and well sites for new wells and for the central area are the same as for conventional oil and gas wells. Refer to the section of the text pertaining to the siting of oil and gas wells under New York State's Oil, Gas and Solution Mining Regulatory Program.

Access roads and the central site have to be scrutinized more closely when pertaining to underground storage in a mined cavern. The conventional mining of a storage cavern large enough for commercial storage of product creates vast quantities of waste rock that must be disposed. It can be stored at the site and reclaimed or it can be transported to an approved disposal site. On-site disposal and reclamation will necessitate the disturbance of a larger land area while the transportation of mined debris will require that access roads be more rigorously designed. This situation will be explained in more detail in the following sections, including the proposed State regulations and mitigation techniques.

#### E. DRILLING OF A MINED CAVERN MAIN SHAFT AND AUXILIARY WELLS

Although it offers a more efficient, easily controlled and monitored storage environment, a gas or LPG mined storage cavern nevertheless must be carved out of solid rock at depths usually greater than 400 feet. To

accomplish this, a central mining shaft measuring between eight and nine feet in diameter is drilled and cased to the top of the storage formation. After the casing cement has set (usually 48 to 72 hours), drilling is resumed down through the interval to be excavated. This main shaft is then used for transporting personnel and equipment underground and for removing the excavated rock (Fenix and Scisson).

The potential environmental impacts associated with the drilling and completion of this large diameter shaft are only slightly different than those for regular oil and gas wells. This stems from the use of mud during drilling operations which acts as a lubricant for the drill bits and drill pipe. It also brings rock cuttings to the surface as they are broken away by the drill bit. Since almost all wells in New York State are drilled with air rather than a lubricating substance such as mud, the current regulations do not provide direction for its removal and disposal. The drilling mud is usually a water-based clay mixture which is not hazardous to the environment. The mud may become polluted during drilling operations by contacting salt water bearing formations or by the addition of chemicals which are used to control the drilling process. Since the main shaft is relatively shallow and it does not penetrate any oil or gas formation, the mud system should remain relatively clean and non-hazardous.

**It is suggested that the ingredients of the mud system and the proposed disposal method be included in the feasibility report submitted to the DEC with the underground storage permit application form.** After assessing the impact of the drilling mud on the environment, the Department will then issue a disposal plan to the operator. If the mud is determined to be clean and non-hazardous then disposal can be accomplished by spreading and tilling the mud into the soil. A hazardous mud will have to be transported to an approved

waste site.

Several one foot diameter auxiliary shafts are also drilled to provide ventilation during mining operations. These shafts are usually converted for injection/withdrawal or pressure monitoring after the cavern is completed. The proposed procedures for drilling and completing these shafts are evaluated by the Department during the review of the storage permit application. This ensures that safe and environmentally sound drilling and completion practices are followed. A permit is required for the conversion of these ventilation shafts to injection/withdrawal wells [6NYCRR 552.2].

Excavation of the cavern can usually begin after the main shaft and ventilation shafts are in place.

#### F. EXCAVATION OF A MINED STORAGE CAVERN

Most storage caverns are mined in sections using the highly developed "room and pillar" method (Marks, 1983). Work progresses by drilling and blasting horizontal tunnels into the rock and then benching downward. By utilizing only 50 percent of the rock in place for permanent roof support, this technique allows for maximum storage per acre (Fenix and Scisson). The LPG storage capacity of the Texas Eastern products Pipeline Company's Facility at Watkins Glen, New York is the State's largest at approximately 50.6 million gallons (NYSDEC, DMN, 1986).

The rock debris created by the mining process is transported to the surface for disposal via the main shaft. The environmentally sound treatment and disposal of this waste rock is a primary concern of the Department. The mined material can be disposed of on-site thus creating a waste rock area, it can be transported off-site for disposal at a waste facility, or it can be sold as aggregate or fill.

##### 1. On-Site Disposal Of Mined Material

The size of the waste rock site at the storage facility depends on the volume

of the cavern being excavated. Waste rock sizes within the pile range from very fine particles to rock fragments greater than twelve inches in diameter. The permeability of the waste rock pile will be high immediately following completion but will decrease over time as fines migrate and plug the voids between rock fragments. The potential environmental hazards associated with the waste site stem from the flow of water through the rock pile which transports sediment to surrounding lowlands and streams. The effects of sediment runoff are detailed in the Siting of Oil and Gas Wells section.

Usually run-off contact with the waste rock is minimal and limited to rock at the periphery of the pile. The sediment loads from the waste rock site will be high for the first few years but are expected to lessen as settling occurs and as the pile becomes vegetated. **To accelerate reclamation where appropriate, seeding and/or mulching of the waste rock pile in conjunction with the application of lime or fertilizer will be required via permit conditions.**

The excavated rock will also cause increased dust emissions. The intensity of this air disturbance will depend on the time of year, the type and amount of excavated material, and the control measures used. Normally, impacts from dust are localized and of short duration. Mitigation techniques such as water spreading on the rock pile will be required should the dust become excessive.

## **2. Off-Site Disposal Of Mined Material**

Disposal of waste rock at an off-site facility will result in increased traffic on local routes and access roads for the duration of the excavation period. Regular servicing of the storage site during operation will also lead to higher than normal traffic levels. Surface requirements for the access roads should therefore be upgraded to handle the increased loads.

Increased impacts from noise, exhaust, and dust emissions are associated with the increased traffic. The impact from noise is dependent upon public exposure to the routes as well as the proximity of the site to the wildlife population. Noise levels will be monitored and any reports of excessive or disturbing noise will be handled expeditiously by the Department. Exhaust impacts will be discussed with the installation of compressor stations in a later section.

Additional environmental impacts are associated with the possible use of generators at the site to provide illumination and power to the mined cavern. The temporary increases in noise and exhaust emissions could be of sufficient volume to warrant specific mitigation measures. Refueling of generators (if gas or diesel fired), transport vehicles, and heavy equipment and discharge of crankcase oil and other lubricants at the site does impose potential environmental and safety hazards. Leaks of liquid fuel from on-site storage tanks could contaminate local habitat and water supplies. The potential also exists for explosions and fires which would endanger wildlife and workers. There are State and EPA regulations governing the stationary storage of fuel if the tank is 1,000 gallons or more, while transporting the fuel is regulated by the Department of Transportation. There are no requirements if storage is less than 1,000 gallons. Site specific pollution problems will be mitigated via storage permit conditions and inspections.

Once the cavern is completed and the mined material has been disposed, a final testing program is implemented consisting of a cavern pressure test using compressed air to test the integrity of the cavern. The compressed air is injected into the cavern until a pre-specified test pressure is reached. The cavern is then shut in and allowed to stabilize for 24 to 48 hours. Pressure readings are then collected hourly to determine if the cavern is tight. The resulting pressure history is evaluated in terms of incremental

pressure changes and final cavern stabilized pressure. If these values do not conform to tolerance levels, then the cavern is re-entered and inspected to determine if remedial work is warranted. After cavern testing is completed, the site is readied for the installation of permanent storage operation equipment. Normally, ventilation shafts are converted for injection/withdrawal but sometimes new wells must be drilled. The following sections detail the drilling of wells and the installation of compressor stations in preparation for actual storage operations.

#### G. DRILLING OF STORAGE WELLS

The number of wells needed for storage depends on whether the storage reservoir is a mined cavern, an abandoned salt cavity, or a depleted gas sand. Natural gas or LPG storage wells are used for injection, withdrawal, and reservoir pressure monitoring and maintenance.

Storage in depleted gas fields will utilize a larger number of wells than storage in a salt cavity or mined cavern. Depleted gas sands such as those in the Medina Group are blanket-type sands that are areally extensive with dynamic boundaries that must be constantly monitored. Gas injection and withdrawal is done at several points within the reservoir to ensure maximum utilization of the sand. The boundaries of a salt cavity or mined cavern remain fixed and the open void volume of a cavity or cavern usually only requires one or two injection/withdrawal points.

The optimum number of wells required for successful storage operations in a depleted gas sand is determined during the reservoir evaluation phase as previously discussed. Idled wells from previous operations are usually converted for storage use when feasible. These wells must be mechanically tight with adequately cemented casing and sound wellhead equipment. The aforementioned storage permit application will include an existing well report



so that the Department can review the condition of these wells. In most cases, new storage wells are drilled in conjunction with the conversion of several existing wells. A permit must be obtained from the Department for any new wells or well conversions [6NYCRR 552.2(a)].

In 1985 there were 841 operating gas storage wells in New York State. Seven hundred forty-nine wells were used for input and withdrawal of gas while the remainder were used for observation and pressure maintenance (NYSDEC, DMN, 1986). The number of wells needed for injection and withdrawal is dependent upon the working pressure of the reservoir and the desired deliverability rate. These topics will be discussed in more detail in upcoming sections.

Storage projects in abandoned salt cavities also utilize wells remaining from previous operations if they can be made mechanically sound. Since leftover wells from solution mining operations are usually few in number, additional wells are drilled to meet the gas deliverability obligations of the storage facility. There are currently nine operational wells for storage of LPG in abandoned salt cavities in New York State (NYSDEC, DMN, 1986).

For mined storage caverns, the major factor in determining the number of wells needed is the desired gas deliverability rate. Numerous reservoir pressure observation wells, common to depleted gas sand storage projects, are not required because of the fixed storage volume of the cavern. Three to four injection/withdrawal wells and possibly one observation well are normally all that is required. Cavern storage wells are prepared for injection/withdrawal in some cases by converting existing mine ventilation shafts and test wells. A new permit must be obtained from the Department for conversion of these wells for injection/withdrawal purposes [6NYCRR 552.2(a)].

Once the storage wells are in place and completed, the facility is readied for gas or LPG injection by installing the compressors and the distribution system. There are presently four operational wells used for LPG

storage in mined caverns in New York State.

#### H. INSTALLATION AND OPERATION OF COMPRESSOR STATIONS

Compressors are needed for storage operations because a) storage in depleted gas fields is conducted at pressures approaching original formation pressure and b) gas may need to be compressed for transmission in high pressure transmission lines. The bank of compressors or compressor station is usually centrally located at the site within close proximity to the gas transmission system.

The number of compressors needed for the particular storage operation is determined during the reservoir evaluation phase prior to applying for an underground storage permit. Total horsepower requirements are estimated by determining the approximate horsepower needed to inject and withdraw gas at maximum rates given the pressure of the reservoir, the number of injection/withdrawal wells, and the desired deliverability rates. The number of compressors needed to supply the calculated horsepower is then installed. The reciprocating compressor is most commonly used in the gas industry because it is designed for a wide range of pressures and capacities. Centrifugal compressors are also commonly used although they do not have high pressure capabilities. In New York, most compressors are driven by natural gas engines.

There are several environmental concerns associated with compressor installation and operation. Transporting and installing the compressors at the central site will cause only temporary visual and noise disturbances. More long term impacts will occur however, from the operation and maintenance of the compressors. The storage requirements of the reservoir will dictate the size and number of compressors needed which in turn will determine the degree of the site's environmental compatability. The bank of compressors is usually

situated on an acre or more of land which has been graded and surfaced. Various utility tie-ins, control panels and outbuildings are located at the site which also serves as the connection point for the wellhead distribution system and the gas transmission lines.

The appearance of the storage facility is considered part of its environmental impact because of the high aesthetic value of the State's natural resources. The most visually affected areas would be those containing population centers, historic landmarks, state parks, or declared conservation areas.

**Due to the site specific nature of visual impacts, provisions for diminishing significant visual impacts associated with compressor location will be recommended as conditions to the storage permit.** Visual screens colored so as to blend with the surroundings may be installed around the perimeter of the site. Locating the compressors amid trees and shrubs would also reduce their unsightliness. When existing vegetation is sparse, new vegetation could be planted around the site.

The environmental impacts on air quality from exhaust emissions due to compressor operation can be estimated based upon the type of equipment used, the hours of operation, and the air conditions. Degradation of the air quality is not a primary concern however, because of the relatively small amount of emissions associated with construction and operation of underground gas storage facilities.

The impacts from the noise generated by the bank of compressors is dependent upon public exposure to the storage site. The size of the land area, the distance to the nearest resident, the prevailing winds, and other factors must be considered. **Storage permit conditions will specify when muffler devices for the compressor exhaust will be required to minimize the noise from the compressor site. Screens or vegetation may also be installed**

**at the site to offer some degree of sound reducing capability.**

The overall environmental impact from installation and operation of a storage facility compressor station will be assessed for each individual site during the storage permit application review period.

#### I. OPERATION OF THE STORAGE FACILITY

After the wells have been drilled and the compressors installed, the storage facility is ready to be brought on-stream. As mentioned previously, gas or LPG is injected during the summer months when consumer demand is low and it is withdrawn during the peak demand winter heating season. The storage field must be able to deliver the peak gas volumes on a daily basis while providing the seasonal volume necessary to supplement the existing winter supply. Since gas is injected and withdrawn on a cyclic schedule, reservoir pressure is controlled within an operating range which is dependent upon the type of reservoir and its depth. The storage cycle pressure range is based upon the safe upper limit of pressure, the flow capacity of the wells, and the compressor requirements for gas injection and withdrawal.

##### 1. Depleted Gas Reservoirs

a. Reservoir Pressure - For depleted gas reservoirs, the upper limit of storage pressure is related to the reservoir discovery pressure which is usually in the range of 0.43 to 0.52 psi/ft. of depth (Ikoku, 1980). The maximum storage capacity and deliverability can be increased by operating the storage facility at pressure levels above the discovery pressure. Since pressures approaching 1.0 to 1.2 psi/ft. of depth could fracture through confining beds and lead to uncontrolled migration of fluids through the porous rocks, the maximum pressure rarely exceeds 0.65 psi/ft. of depth with good caprocks although 0.70 psi/ft. of depth has been used safely in the field (Ikoku, 1980). The lower pressure limit is usually set high enough to

overcome water intrusion at lower pressures while maintaining sufficient flow capacity for the wells.

The following table details the pressure characteristics for the Medina and Oriskany Sandstone reservoirs that comprise 19 of the State's 21 gas storage fields:

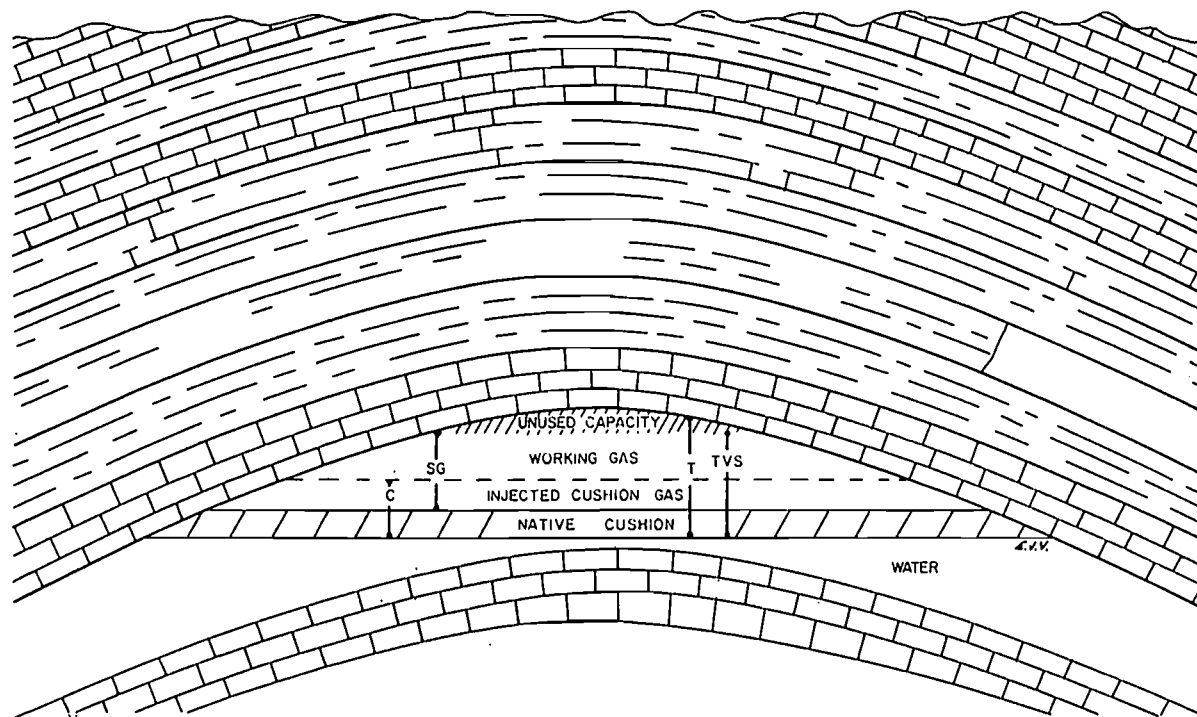
	Medina	Oriskany
Average Depth (ft)	2,423	4,551
Average Discovery Pressure (psig)	820	2,002
Gradient (psi/ft)	0.34	0.44
Maximum Operating Pressure (psig)	779	2,012
Gradient (psi/ft)	0.32	0.44
1985 Maximum Average Operating Pressure (psig)	724	1,729
Gradient (psi/ft)	0.30	0.38

Gas storage operators have fixed their maximum storage reservoir pressure at or near the average discovery pressure for Medina and Oriskany reservoirs. The actual field-wide operating pressure will vary during the year as gas is injected and withdrawn. Pressure surveys taken in the fall will reflect maximum conditions because of the injection of gas during the summer. Springtime surveys will reveal low pressure due to gas withdrawal for the winter heating season. The maximum average operating pressure gradient as reported in 1985 for the Medina and Oriskany was approximately 0.30 psi/ft. and 0.38 psi/ft., respectively.

b. Segments of a Gas Storage Reservoir - Most natural gas storage reservoirs can be divided into four basic segments as detailed in Figure 14.6. Cushion gas is a gas reserve which is required to maintain reservoir pressure at a base level to provide adequate gas deliverability rates throughout the withdrawal season. The total cushion gas volume is comprised of injected gas from external sources and native gas that was in place at initiation of storage operations. Cushion gas is also known as base gas and is part of capital investment (Ikoku, 1980). It is normally held permanent within the reservoir and is not available for delivery. In times of energy emergency

FIGURE 14.6 SEGMENTS OF A GAS STORAGE RESERVOIR

T = TOTAL RESERVOIR CAPACITY  
 TVS = TOTAL VOLUME OF GAS IN STORAGE RESERVOIR  
 SG = STORED GAS (excludes all native gas)  
 C = CUSHION GAS



however, portions of the cushion gas may be withdrawn. From 20 to 75 percent of the cushion gas will be recovered at abandonment of the facility, depending upon reservoir heterogeneity (Ikoku, 1980).

The gas that is injected and withdrawn seasonally is called working gas. Also known as top or circulating gas, it is that portion of the total storage gas that is available for delivery.

The unused capacity is that portion of the reservoir presently underutilized but available for additional storage. It is mainly a function of operating pressure although the reservoir characteristics of the storage formation will also dictate ultimate gas storage volumes.

From an economic standpoint, it is desirable to have as much working gas capacity as possible in the storage reservoir for delivery to the consumer. The volume of working gas will be limited, however, by the amount of cushion gas needed to maintain the pressures required for adequate gas deliverability during peak demand periods. The following table shows the volumes and percentages of working gas, cushion gas, and unused capacity for the 21 natural gas storage projects in New York State (as of 12/31/85) (NYSDEC, DMN, 1986).

	<u>Totals (MMCF)</u>	<u>Percent</u>
Cushion Gas	85,403	48.4
Working Gas	53,072	30.1
Unused Capacity	<u>38,080</u>	<u>21.5</u>
Total	176,555	100.0

c. Operation of a Gas Storage Reservoir - The overall operation of a natural gas storage facility is dependent upon two critical factors - the total volume of gas that will be required during the peak demand heating season and the daily delivery rates for that volume. The seasonal fluctuations in gas demand stem from the two-part gas requirements of the domestic gas consumer. The fixed load gas is that volume needed to run

appliances, water heaters, clothes dryers, etc. This load remains fairly constant throughout the year. The space heating gas is that used in furnaces, heating stoves, etc. This load fluctuates tremendously thus requiring a back-up supply system such as that offered by underground gas storage (Borland, 1957).

The space heating gas demand is determined by the utilities by studying gas consumption in relation to U.S. Weather Bureau reports of the market area. The average domestic gas consumer starts to use gas for space heating purposes when the average daily temperature drops below 65°F (Borland, 1957). Each degree below 65°F in the average daily temperature is called a degree day deficiency. An average daily temperature of 60°F would result in 5 degree day deficiencies.

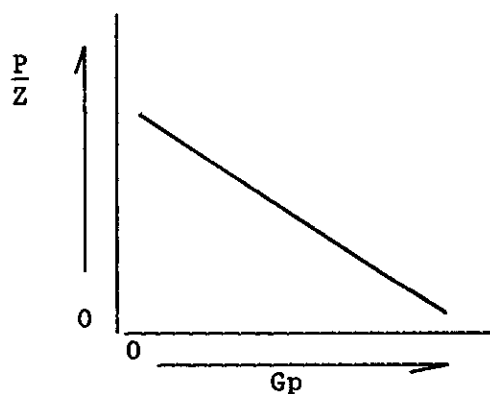
Studies of past year's gas consumption yield an average consumer gas requirement expressed in terms of cubic feet of gas per day for every degree below 65°F. This value is multiplied by the number of degree day deficiencies in an average winter and the number of gas consumers to determine the total space heating load requirement for a particular market area. There is a variation of about 20 percent from the average figure for gas requirements during extremely cold or warm winters. The peak gas demand on a daily basis is calculated in the same manner from the degree day deficiency of the coldest days during the winter. These estimates are then made available to the wholesale gas suppliers so that they can determine optimum gas storage volumes and peak supply rates (Borland, 1957).

Given the peak market demand from storage on a seasonal and daily basis, the total well and compression requirements are determined for minimum investment and operating expense (Katz, et. al., 1958). Enough injection and withdrawal wells are drilled to provide the needed flow capacity from the field.



During the gas withdrawal season, a storage field often produces a volume of gas equal to approximately one-half of its initial content in only three to four months. Because rapid decreases in reservoir pressures will occur, shut-in pressure observation wells which reflect the pressure in the bulk of the reservoir are required to ensure safe and efficient operation of the reservoir. These pressure monitoring and observation wells are located throughout the storage reservoir to better represent field-wide pressure conditions. Specific observation wells are also located near the boundaries of the storage reservoir or near any area where pressure fluctuations and/or gas migration may occur.

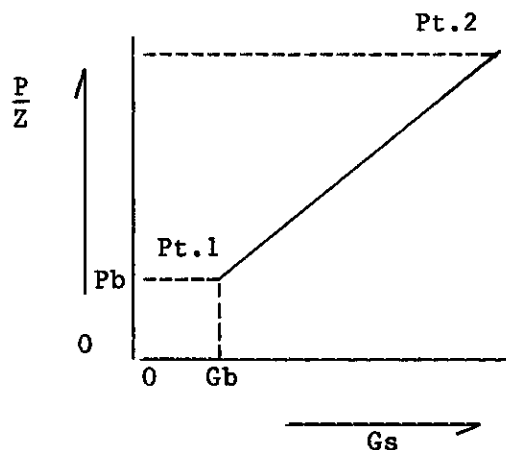
The monitoring wells are usually converted from old gas wells but new wells will usually be required for specific observation purposes as detailed above. By monitoring and gathering storage reservoir pressures on a routine basis, estimates of the gas volume in storage can be made. For volumetric gas reservoirs with no water encroachment and negligible water production, the relationship between gas production and reservoir pressure can be expressed as a straight line as shown by the following graph.



$P$  = reservoir pressure (psig)  
 $Z$  = gas compressibility factor @ pressure  $P$   
 $G_p$  = cumulative gas production (MMSCF)

This relationship can be used to determine the behavior of a gas storage reservoir by plotting storage reservoir pressure versus gas volume in storage.

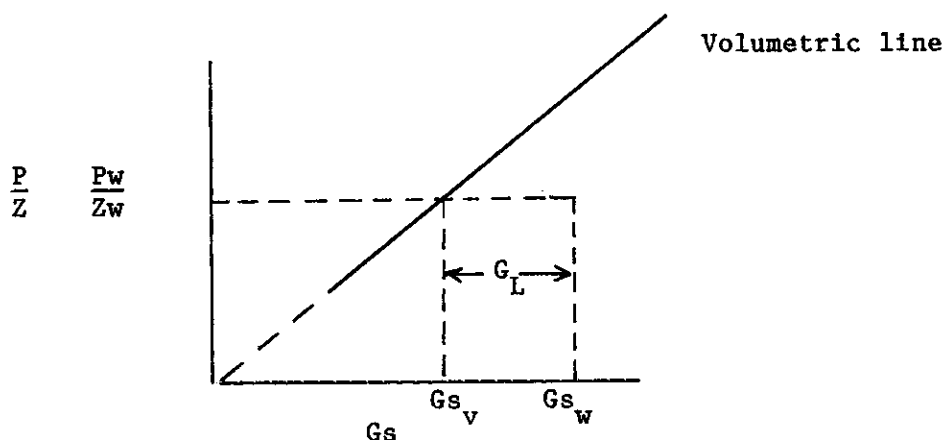
First, the theoretical performance line must be constructed which is based on the maximum and minimum operating conditions of the reservoir. Prior to initiation of storage operations, the reservoir is in a depleted state with an unrecoverable amount of gas in place at a specific pressure. Cushion and working gas are then injected until the reservoir reaches its storage capacity with a corresponding peak static reservoir pressure. If volumetric reservoir behavior is assumed, a straight line between these two points will yield the storage reservoir's pressure/volume relationship. The following graph details these points.



$P$  = reservoir pressure (psig)  
 $Z$  = gas compressibility factor @ pressure  $P$   
 $G_s$  = gas volume in storage (MMSCF)  
 $b$  = base, or depleted reservoir conditions  
 Note: Expanded definitions and additional theory are included in the appendix.

At Pt. 1,  $G_s$  is given by the base gas ( $G_b$ ) at pressure  $P_b$ . At Pt. 2,  $G_s$  is the base gas plus the added cushion and working gas which corresponds to a maximum static pressure. During the course of storage operations, fixed amounts of gas are injected to and withdrawn from the working volume. Plotting the pressures associated with the changes in volume should yield estimates of reservoir storage behavior. Gas losses from the storage reservoir are indicated when the storage pressure term ( $P/Z$ ) falls below the

volumetric line after a given amount of gas is injected or withdrawn from storage. An estimate of the amount of gas "lost" from the reservoir can be estimated from the performance graph as illustrated below.



- $P_w$  = field pressure after withdrawal of gas (psig)
- $Z_w$  = gas compressibility factor @  $P_w$
- $G_{s_w}$  = total gas storage volume after withdrawal of a known quantity of gas (MMSCF)
- $G_{s_v}$  = volumetric total storage volume corresponding to  $P_w$  (MMSCF)
- $G_L$  = theoretical gas "lost" (MMSCF) =  $G_{s_w} - G_{s_v}$

For the case of gas storage in the presence of a strong water drive, the encroaching water will diminish the amount of reservoir pore volume available for storage. This in turn causes the storage pressure to remain falsely high for a given volume of gas in storage. The theoretical pressure/volume equations and the calculation procedures for storage in a water drive reservoir are similar to those for dry storage reservoirs except that water production and water influx are accounted for. This discussion concerning the monitoring of gas storage volumes is based on the technical report included in the appendix. More precise definition of the equations and calculations involving gas storage can be found in this report.

These calculations are not intended to pinpoint the gas losses from the reservoir but rather to qualify the storage project in terms of efficiency and environmental safety. Inefficient storage operation will result in lost

revenue for the operator and decreased taxes to the State. Losses may also be significant enough to limit the gas supply during peak demand conditions. In addition, the environmental problems associated with unchecked gas migration can be better defined and mitigated by identifying problem storage projects.

## 2. Mined Caverns And Abandoned Salt Cavities

Storage pressure requirements are somewhat different for mined caverns and salt cavities than for depleted gas reservoirs. Presently, caverns and cavities are used exclusively for LPG storage in New York State, although Brooklyn Union Gas Company is considering a natural gas storage cavern project in New York City. The absolute minimum reservoir pressure must be sufficient enough to overcome the vapor pressure of the product. At lower pressures, vapors would accumulate in the reservoir which would then be compressed as more product were added. If the temperature of these compressed vapors was to increase, a dangerous situation could arise. Caverns and cavities selected for storage operation are therefore usually at a depth great enough to offset the stored product's vapor pressure based on a gradient of .43 psi/ft., of depth.

Since the reservoir depth is designed to control vapor pressure, the actual minimum operating pressure is selected based on the designed minimum deliverability of the facility. For salt cavities this pressure must also be sufficient to control integrity by preventing salt intrusion. The maximum reservoir pressure for both types of reservoirs is usually limited by that pressure that would cause uncontrolled product migration from the storage reservoir by overcoming the geostatic forces acting on the cavern or cavity. The following table summarizes the operating parameters for the three active LPG storage facilities in New York State.

<u>Operator</u>	<u>Western Energy</u>	<u>Bath Storage</u>	<u>Texas Eastern</u>
County	Cortland	Steuben	Schuyler
Depth (ft)	2,900	2,946	460
Storage Pres- sure (psi)	1,100	1,000	105
Gradient (psi/ft)	.38	.34	.23
Storage Capa- city (Mgal)	20,000	34,846	50,568
Storage Bal- ance (Mgal) as of 12/85	0	12,483	31,333
Wells	3	6	4

Whereas over 800 operating wells are required for the State's 21 natural gas storage projects in depleted gas reservoirs, only 13 are utilized for injection and withdrawal of LPG. This is mainly due to the high product deliverability offered by cavern or cavity storage compared to depleted gas fields.

### 3. Regulation Of Storage Operations

In regulating the State's storage industry, the Department is responsible for ensuring the safe and efficient operation of storage facilities while monitoring their environmental compatability. Of primary concern are the annual changes in product storage volume and the year-end storage balance as a percentage of total reservoir capacity. Gas or LPG migration to surrounding formations could result in problems for offset operators while decreasing the effectiveness of the storage facility to augment energy supplies.

The condition of storage and monitoring wells in terms of casing and tubular corrosion as well as wellhead equipment is also very important to the Department. Improperly cemented or corroded wellbores would offer a direct path for product leakage to the water table or the surface thus causing significant environmental damage or public safety problems. Surface leakage of gas or LPG in close proximity to compressors or other surface equipment

could cause explosions and extensive damage.

The existing law states that storage operators must submit a status report before December 31 of each year which summarizes that year's storage activities [ECL 23-1301.4]. **It is suggested that new regulations specify that the report be submitted by March 1 to allow operators time to assemble and assess their storage data.** The report includes the following:

- a. Any change in the estimated size in surface acreage or shape of the reservoir and the buffer zone.
- b. The total capacity of the reservoir.
- c. The working capacity of the reservoir.
- d. Any other engineering, geological or operational data that may be requested by the Department.

Additional data required on the existing Operator's Annual Natural Gas Storage Report form includes reservoir discovery pressure, maximum storage pressure, and average field pressure; number of operating and observation wells, number of wells with casing failures or leaks, and number of wells surveyed for corrosion. Similar information is included on the Operator's Annual LPG Underground Storage Report.

This data is used by the Department to identify those storage projects that may be operating negligently or inefficiently. **It is recommended that regulations be formulated to identify specific infractions as deemed important by the Department and the mitigation techniques that will be required to rectify or alleviate them.** Following are some specific infractions and possible solutions that will be addressed.

- a. Unauthorized expansion of the storage reservoir as shown by the maximum storage volume or storage balance exceeding the reservoir's total capacity. If the Department allows this expansion after reviewing the ramifications, then a storage capacity modification

fee of five thousand dollars will be assessed pursuant to ECL 23-1301.5 as amended by the 1984 Session Laws.

- b. Operating at a maximum field pressure which exceeds the approved design pressure. The Department will require that a sufficient volume of gas or LPG be withdrawn from the storage reservoir to lower the pressure to acceptable levels.
- c. Refusal to submit corrosion testing data on storage wells. Upon request, the operator will have to prove to the Department that all storage wells are in good mechanical condition in lieu of corrosion studies.

In addition, the annual report form will be amended to include the actual amounts of cushion gas and working gas that make up the year-end storage balance.

Although an underground storage permit as issued by the Department is in force indefinitely, some storage projects may be abandoned due to inefficient operation or a decrease in market demand.

#### J. ABANDONMENT OF UNDERGROUND STORAGE FACILITIES

Because of the constant need for increased energy supplies during the winter heating season, the abandonment and dismantling of an underground storage facility is a rare occurrence. The average age of the 21 natural gas storage projects currently operating in New York State is 30 years. Most recently, the International Salt I and II LPG storage facilities were depleted and shut-down at the end of 1984.

The Department is primarily concerned with the proper abandonment of wells, the proper clean-up and restoration of disturbed surface areas, and the status of the abandoned storage reservoir.

## 1. Well Abandonment

For well abandonment in depleted gas sands, the rules and procedures are the same as for regular oil and gas wells. See the section dealing with the plugging and abandonment phase of well operations for details on the State's proposed abandonment regulatory program.

**It is recommended that new regulations include specific abandonment procedures pertaining to wells in mined storage caverns or abandoned salt cavities. An adequate seal must be fabricated to isolate the well bore from the cavity or cavern so as to limit transferral of fluids, debris, etc., to or from the reservoir and adjacent formations. This could be accomplished by placing a permanent packer in the casing at the top of the storage formation and spotting a quantity of cement on top of the packer.**

## 2. Site Restoration

The existing oil and gas legislation states that the premises of previous storage operations shall be placed in a condition which does not constitute a menace to the present or future health or safety of persons, or safety or value of property [ECL 23-1305]. If an operator fails to meet his obligations as determined by the State, the Department may act to place the premises in satisfactory condition with the operator being liable for the cost.

Reclamation procedures for clean-up of compressor sites, buildings, access roads, etc. will be specified as permit conditions. Restoration of well sites will be governed according to the regulations pertaining to well abandonment.

Environmental impacts from reclamation procedures will consist of temporary noise and dust emissions as sites are graded and cleaned. Short term increases in traffic on access roads and local routes will be realized as compressors are removed and equipment is transported. The planting of trees and shrubs may be required to restore the area to original conditions.



### 3. Reservoir Abandonment

The final status of the storage reservoir at the time of abandonment of storage operations is of utmost concern to the Department. Presently, there are no regulations governing reservoir abandonment procedures or documentation practices. A reservoir cannot be abandoned like a well or location, but its status can be assessed and reported. It is suggested that operators be required to submit an operational report summary when storage operations are terminated at the facility. This report should contain the following information:

- a. A brief history of storage operations including start-up and termination dates along with dates of significant events or changes in operations.
- b. Initial fluids in-place and total volumes cycled through the reservoir.
- c. Final fluids remaining in the reservoir at abandonment including the amount of native gas, if any.
- d. Operating pressure summary over the life of the project. A final abandonment pressure survey will be required.
- e. Any other information that the Department may require.

The existing oil and gas legislation states that all gas and LPG that has been reduced to possession and has been lawfully injected into a storage reservoir, shall remain the property of the injector, his heirs, successors, or assigns [ECL 23-1307.1]. This does not include native amounts of gas or LPG that existed in the reservoir prior to initiation of storage operations unless rights to the native gas have been secured by lease or acquisition. The operating pressure summary will be used to assess the integrity of the reservoir, cavity, or cavern. A particular problem area exists concerning abandonment of a salt cavity or mined cavern after withdrawal of storage

fluids. Mined caverns are designed to support themselves regardless of fluid volumes in storage so that collapse of the abandoned cavern is highly unlikely. Leaching water into the cavern over time may cause some sloughing which could compromise the cavern's integrity. Natural disasters such as earthquakes might also pose problems. Since caverns are constructed in relatively shallow bedrock, collapse of the cavern could cause subsidence problems at the surface.

An abandoned salt cavity is far more likely to suffer sloughing or collapse of some kind because of the stratified nature of salt beds. Since layers or "ledges" of insoluble rock occur in most bedded salt deposits, creation of a solution cavity will cause the ledges to become undermined (Piper, 1970). The caving-in of these rock layers will cause a debris pile to accumulate in the cavity as shown in Figure 14.4. Since the salt formations used for storage in New York State are at an average depth of 2,900 ft., pollution of freshwater formations is highly unlikely. Nevertheless, the Department will review salt cavity abandonments to determine if specific mitigation plans are required. Filling the cavity void with foamed cement, saturated brine, or other slurry materials may be warranted.

#### **4. Underground Storage Abandonment Permit**

**In order to ensure complete review of storage reservoir abandonment operations by the Department, it is suggested that new regulations require that an underground storage abandonment permit be obtained by the operator. The Department's permit review process will consider reservoir abandonment techniques if needed, as well as surface restoration procedures to be followed. It is recommended that the application for the abandonment permit will be in the form of an abandonment summary filed by the operator containing the following information:**

- a. A map detailing the final reservoir and buffer zone boundaries.  
Access roads, compressor site(s), and well locations will also be shown.
- b. The reservoir abandonment report as discussed previously.
- c. Any other information as required by the Department.

A large amount of emphasis will be placed on abandonment of a storage project because of the potential long term effects of storage operations on the environment and local communities.