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NATURAL SODA

2010 Mine Plan
Volume 4, Section 6.0
Mine Plan

Prepared for:

Natural Soda, Inc.
Piceance Creek Basin
Rio Blanco County, Colorado

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TABLE OF CONTENTS

LIST OF FIGURES

Appendices

6.0 Section 6 – Mine Plan

6.1. Introduction

Natural Soda, Inc. (NSI) operates a commercial-scale, saline mineral, solution mine on Sodium Lease Numbers C-0119986, C-0118326, C-0118327 and C-37474, located in Township 1 South, Range 98 West, in all or parts of Sections 15, 16, 17, 21, 22, 23, 25, 26, 27 and 28. Figure 6-1 depicts NSI's general location, while Figure 6-2 shows the plant facilities and project area.

The plant was originally permitted to produce sodium bicarbonate at a rate of 125,000 tons per year. BLM's project approval was issued in a Nov. 20, 1987 Record of Decision. This section of the Mine Plan presents NSI's saline mineral solution mining plan and describes various facets of the mine, processing facility and regulatory requirements. Additionally, NSI wishes to present information regarding its plans for future mining methods and intervals, as well as future production capabilities. NSI has endeavored to develop a mine plan that maximizes the utilization of the sodium resource in a manner consistent with the public's goals of preserving the environment, natural resources, recreational and aesthetic qualities of the area. The economic benefit is shared with the public through royalty payments, taxes and employment. All operations have been and will be conducted under an approved Mine Plan.

As of the date of this report, NSI's production output is approaching the current facility design production limits (for phase 1 construction) and the current regulatory permitted production limits. Intelligent growth coupled with advances in technology and an ongoing research, development and demonstration (RD&D) plan are keys to a company's success. As such, NSI plans to enter into a plant expansion program designed to incrementally increase production capability to 250,000 tons per year (TPY). Completion of plant expansion is anticipated in 2012, with stepped production increases approaching plant capacity around 2016.

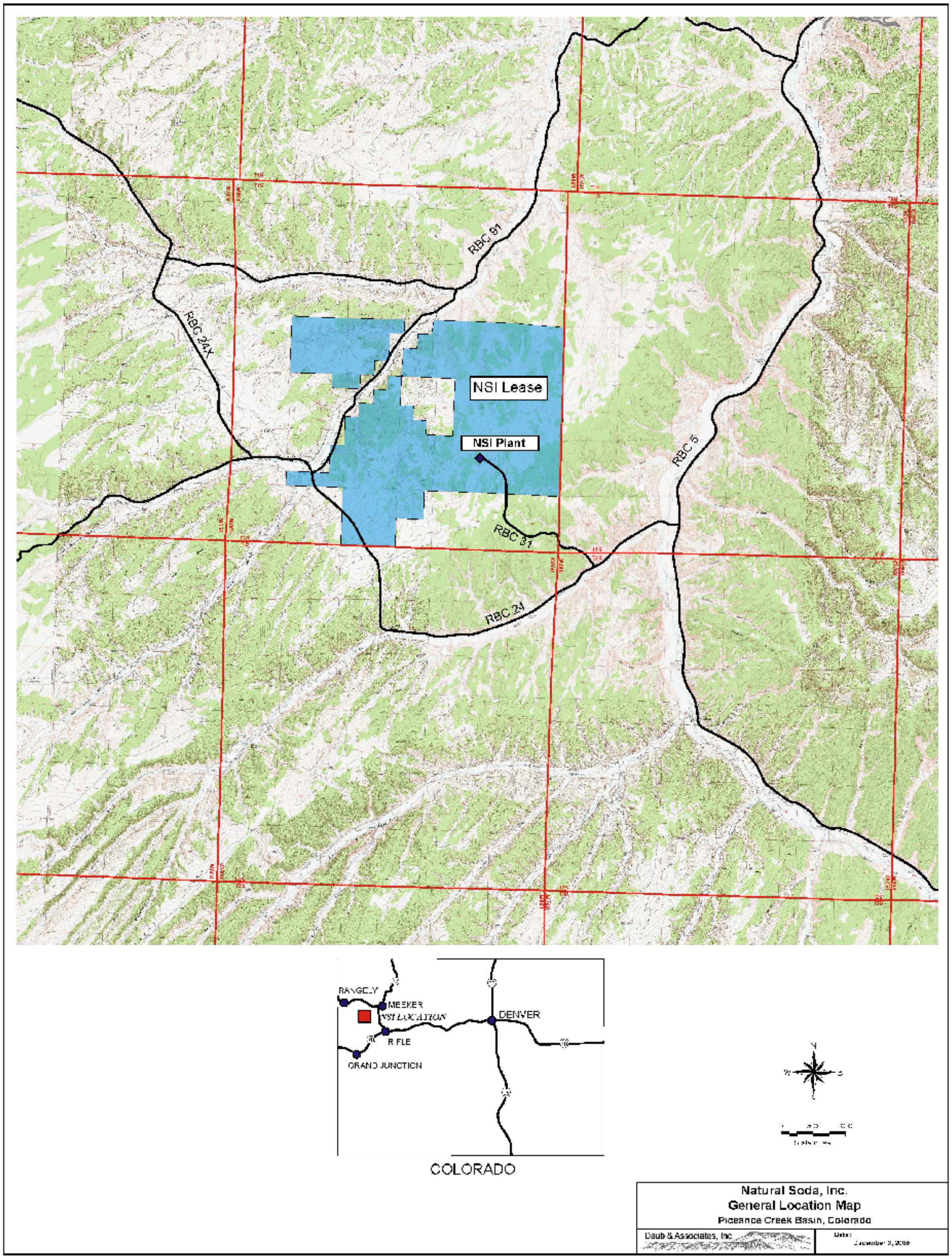

Figure 6-1. General Location Map

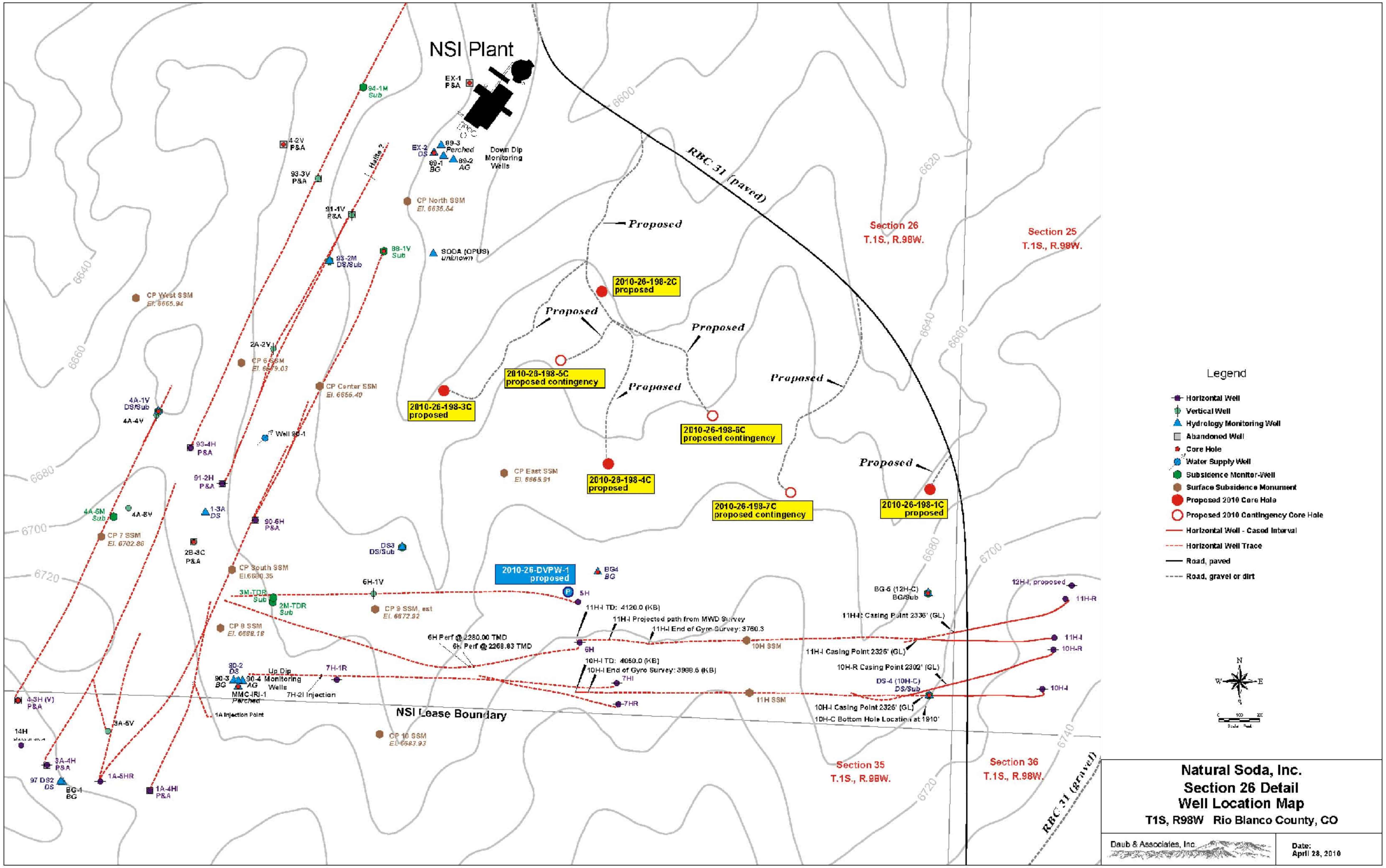

Figure 6-2. Natural Soda, Inc. Plant Facilities and Project Area Map.

Concurrent with the plant expansion, NSI will move forward by continuing to better define the currently targeted nahcolite resources in the Boies Bed and potentially add saline mineral extraction capability to additional segments of the Saline Zone with the upcoming Deep Vertical Production Well (DVPW) RD&D project. Details of these various elements may be found in this and following sections.

Simultaneous resource recovery by others in the area of NSI's solution mining efforts mandates heightened awareness and due diligence from all parties involved. NSI will continue to engage in best practices and will encourage an open dialogue among all parties. Potential benefits and opportunities that communication and cooperation offers include resource protection and the possibility of shared knowledge and infrastructure, thereby potentially reducing costs and disturbance to public lands.

6.2. Mine Plan Strategy

The primary mine plan goals are to economically mine saline minerals by optimizing resource recovery, protect underground sources of drinking water and preserve oil shale assets. While the nature of this plant requires a flexible mine plan, a predetermined basic strategy is necessary. The core elements of this strategy are:

- Position mining intervals for optimum resource recovery.
- Mine individual intervals to operational exhaustion.
- Closely monitor potential effects of mining on underground sources of drinking water (USDW) aquifers.
- Protect USDW aquifers by cementing well annuli to surface per Underground Injection Control (UIC) permit.
- Control Dissolution Surface aquifer pressure, thus preventing water movement from Dissolution Surface aquifer to B-Groove aquifer.

6.3.2. Production Rates

The facilities were originally constructed to produce 125,000 tons per year of high-grade sodium bicarbonate, while operating seven days per week, 24 hours per day, and with an 85% on-stream factor. Planned plant expansion (2010-2012) will increase production capability to 250,000 TPY. Production will be shut down in accordance with Item 1, Appendix A, of the 1987 Record of Decision until a plan for mitigation is accepted by the Authorized Officer, should the monitoring indicate that significant impacts are occurring which were not anticipated in the EIS.

6.3.3. Oil Shale Protection Lease Restriction

The EIS states that "Insignificant direct damage to overlying oil shale resources will occur as a result of drilling (i.e. the portion of rock that is drilled out will be destroyed or removed). If wells are properly constructed and properly abandoned, this damage will be more than offset by the information on the oil shale that will be obtained from the drill holes. No adverse impact is expected on the quantity, quality or future recoverability of the overlying oil shale; however, monitoring of the sodium cavities and overlying formations will be required to confirm this prediction. No impact to the oil shale resources below the Boies Bed is expected." Agapito Associates, Inc. has concluded in two separate reports, prepared in 1995 and 2002, respectively, that high extraction mining within panels as planned by NSI is possible without adverse impact on the minability of the Mahogany oil shale zone or to the USDW aquifers.

6.4. Mining Stratiform Nahcolite

6.4.1. General Process

NSI currently recovers nahcolite by in-situ solution mining of the Boies Bed, a deposit near the top of the Saline Zone and within tens of feet of the Dissolution Surface (DS) and on the bottom by the top of the R-5 oil shale zone. Hot unsaturated (barren) brine

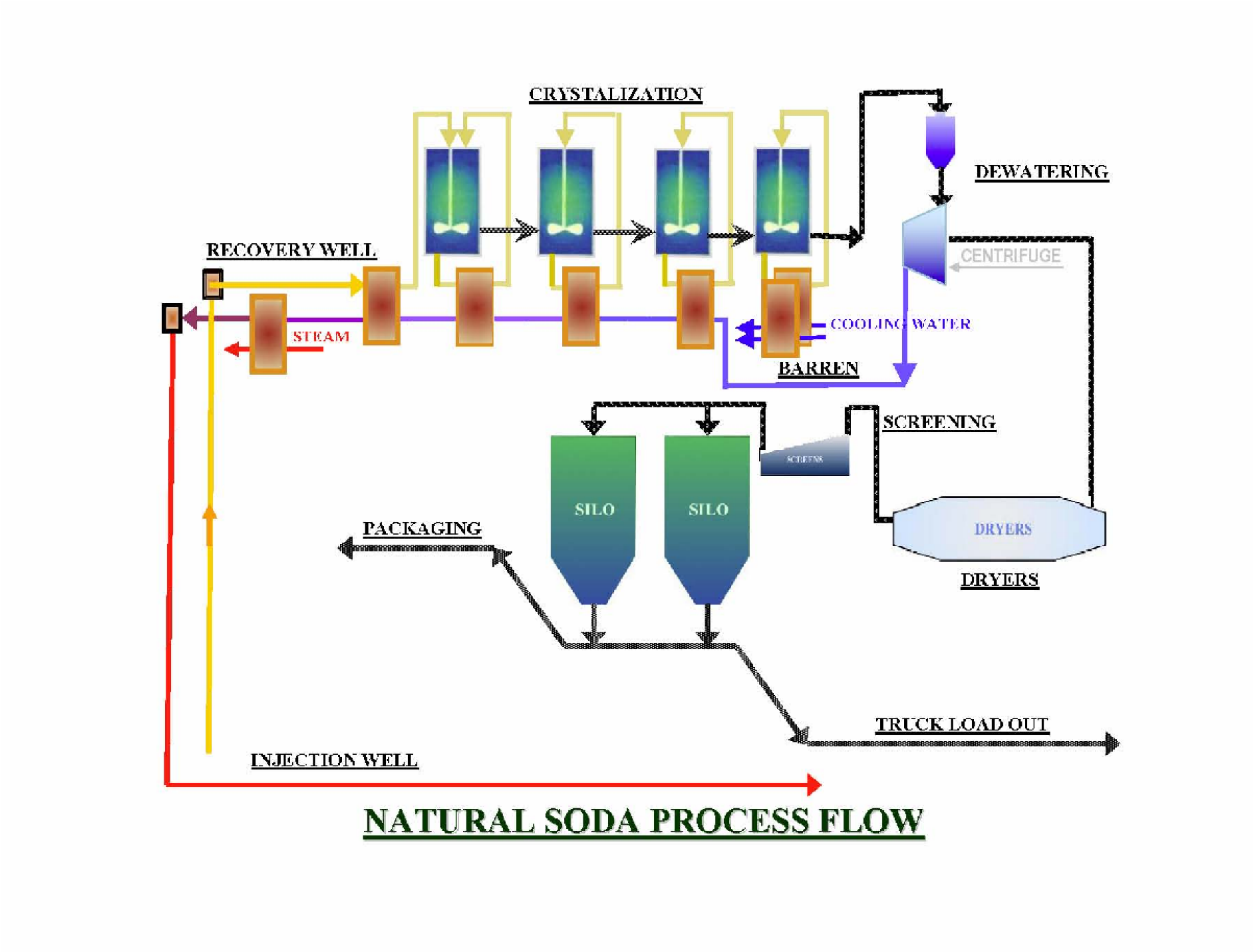

Figure 6-3. Process Flow Diagram

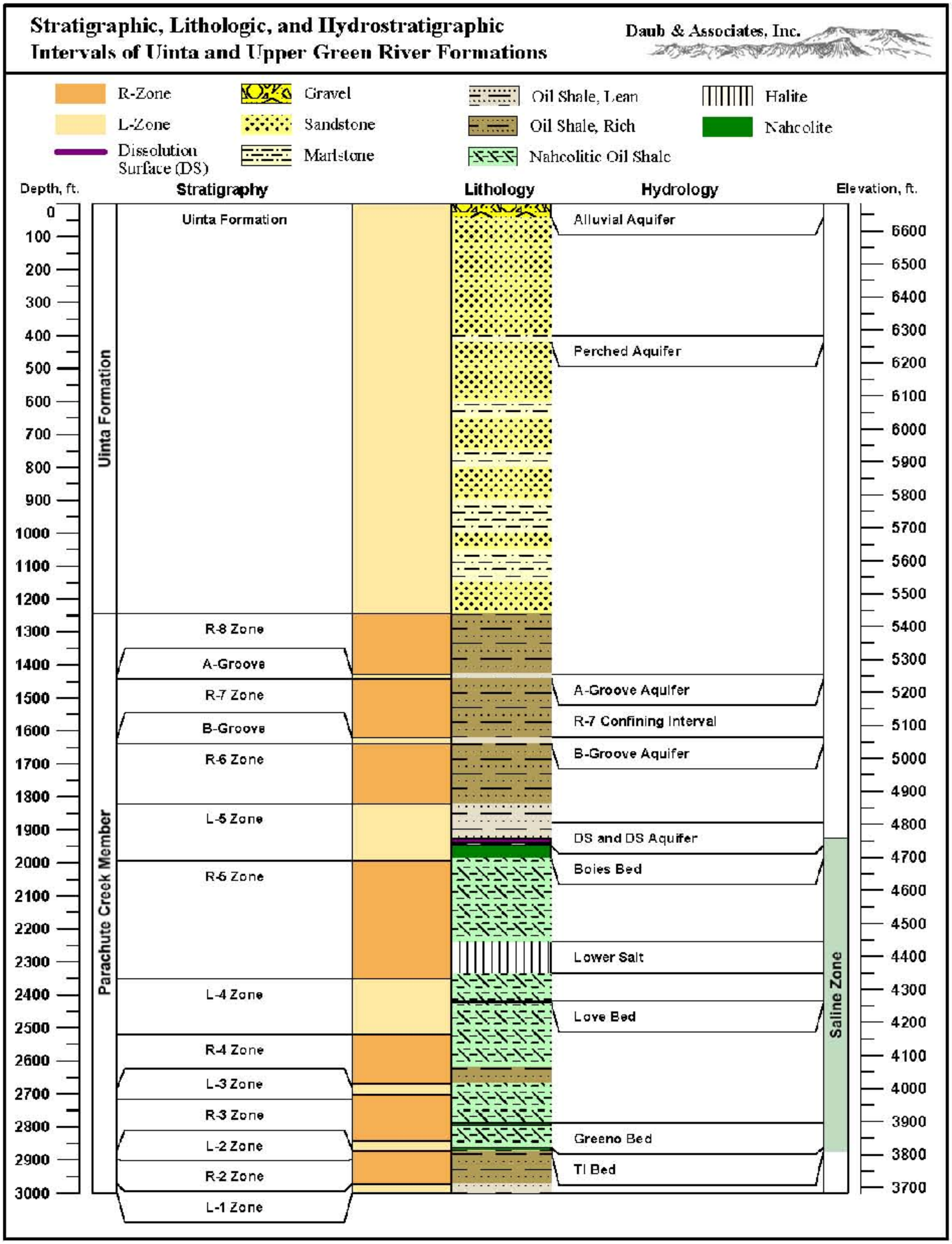

Figure 6-4. General Stratigraphic Column of the Piceance Creek Basin.

The thickness of the nahcolite deposit decreases to the southwest of the plant. To the northeast of the plant area, stratiform halite replaces the nahcolite in a bed by bed replacement from the bottom of the L-5A bed upward.

Non-stratiform nahcolite exists as aggregates, nodules or individual crystals formed just below the fluid / lake bed interface and within the organic rich sediments. The oil shale containing the non-stratiform nahcolite is the focus of NSI's 2010 RD&D Deep Vertical Production Well (DVPW) activity. All of NSI's injection wells are permitted through EPA Class III UIC permits. Additional discussion of NSI's 2010 RD&D effort may be found in Section 6.6

6.4.3. Groundwater

Oil shale above the mining interval provides little primary porosity for groundwater storage. Aquifer storage is principally secondary porosity resulting from fracturing and dissolution of the preexisting stratiform and non-stratiform saline minerals, and is found in pits, vugs, and solution cavities. Within the lease area, four (4) groundwater aquifers are recognized: the Perched Aquifer, the A-Groove Aquifer, the B-Groove Aquifer and the Dissolution Surface Aquifer. The Mahogany Zone, a leaky, semi-confining oil shale, separates the A and B-Groove aquifers. Process water is currently supplied to the plant from an A-Groove water supply well (90-1). Pump tests have established that water pumped from the 90-1 water supply well creates a 360-degree inward flowing cone of depression. A coinciding cone of depression is transmitted to the B-Groove aquifer through fractures in the leaky, semi-confining Mahogany Zone. However, the cone of depression is not transmitted below the B-Groove to the Dissolution Surface (DS) Aquifer. The DS Aquifer is isolated from the B-Groove Aquifer by a 250-foot thick fractured oil shale confining layer, known as the Leached Zone. Baseline hydrologic exploration determined that the piezometric pressure in the DS Aquifer is slightly less than the pressure in the B-Groove Aquifer. In an open exploration hole, it was observed that the A and B-Groove waters moved downward and entered the poorer quality water of the DS Aquifer. This pressure gradient and flow direction protects the A and B-Groove aquifer water quality.

Although both the A and B-Groove waters, near the basin depocenter, are of poorer quality, both are protected as potential underground sources of drinking water (USDW). The on-going natural leaching of saline minerals in the DS Aquifer result in total dissolved solids (TDS) concentrations greater than 10,000 ppm. Therefore, the Environmental Protection Agency (EPA) does not consider the DS Aquifer to be a potential USDW. Above the A-Groove, the Perched Aquifer lies in the Uinta Formation sandstone layer. This sandstone layer has variable porosity due to natural cementation. The Perched Aquifer is discontinuous and is a minor regional component of the groundwater system.

6.4.4. Operating Plan

A key element of this mine plan is the control of the DS Aquifer piezometric pressure such that the A and B-Groove Aquifers are not impacted by saline water from the DS Aquifer. Redundant operational controls and continuous DS monitoring feedback are utilized. Operational controls include: the plant water inventory balance, control of injection and recovery rates, production well and DS Aquifer piezometric data. The inventory balance and flow rate management allow operational control while more precise control is provided by continuous water level monitoring via pressure transducers. Water quality and fluid level monitoring information is included in the NSI Comprehensive Monitoring Plan (submitted under separate cover). Additional information on the operation can be found in various subsections of this part of the Mine Plan (Section 6.0).

6.4.5. Mining Methods

Various methods of mining have been employed to recover saline minerals, including directionally drilled horizontal production and/or injection wells; and, vertical production and/or injection wells. Dual horizontal wells have proven to work quite well for solution mining in the stratiform Boies Bed. In addition, currently unknown mining methods and technological advances may be identified and employed in the future.

For the recovery of stratiform saline minerals, directionally drilled horizontal wells can be either injection or recovery wells and can vary in horizontal length from 100 feet to approximately 3,500 feet. Upon well completion, mining begins and the cavity is developed. Various types of well configurations have been used to develop cavities using this method: one method uses two horizontal wells, which are interconnected at a strategic point; another method utilizes one long horizontal well and a single or multiple vertical well(s) that intersects the horizontal well. A third, less preferred, method utilizes horizontal wells which are connected into existing horizontal wells at various angles. This plan does not cover every type of configuration available, but tries to indicate the wide range of diversification required to meet production requirements tempered by capital constraints.

Vertical Wells tend to be multipurpose wells, i.e. production and/or injection wells. These wells may be located at strategic points along cavities formed by using the directionally drilled horizontal wells. To ensure the cavities are developed symmetrically, these wells may be orientated and located based on the dip, thickness and grade of the Boies Bed. These wells can be alternated from injection to recovery and back to control cavity growths and shape. Additionally, vertical wells may be mined as an independent interval, providing an alternative to horizontal borehole mining. The vertical wells also provide a larger directional-drilling target and can act to create a sump for settling insolubles and aid in the recovery of more saturated solutions. Well construction would be similar to vertical wells used for horizontal borehole mining but with an additional string of casing. This mining method also offers research and development opportunities and may improve the efficiency and predictability of horizontal mining.

Any of the above mining methods may be used with controlled leaching techniques. For example, undercutting is a common solution mining practice, in which an inert fluid cap is placed near the top of the mining interval to improve the vertical to horizontal leach rate. Cap material is commonly propane, methane, air, nitrogen or other inert gas.

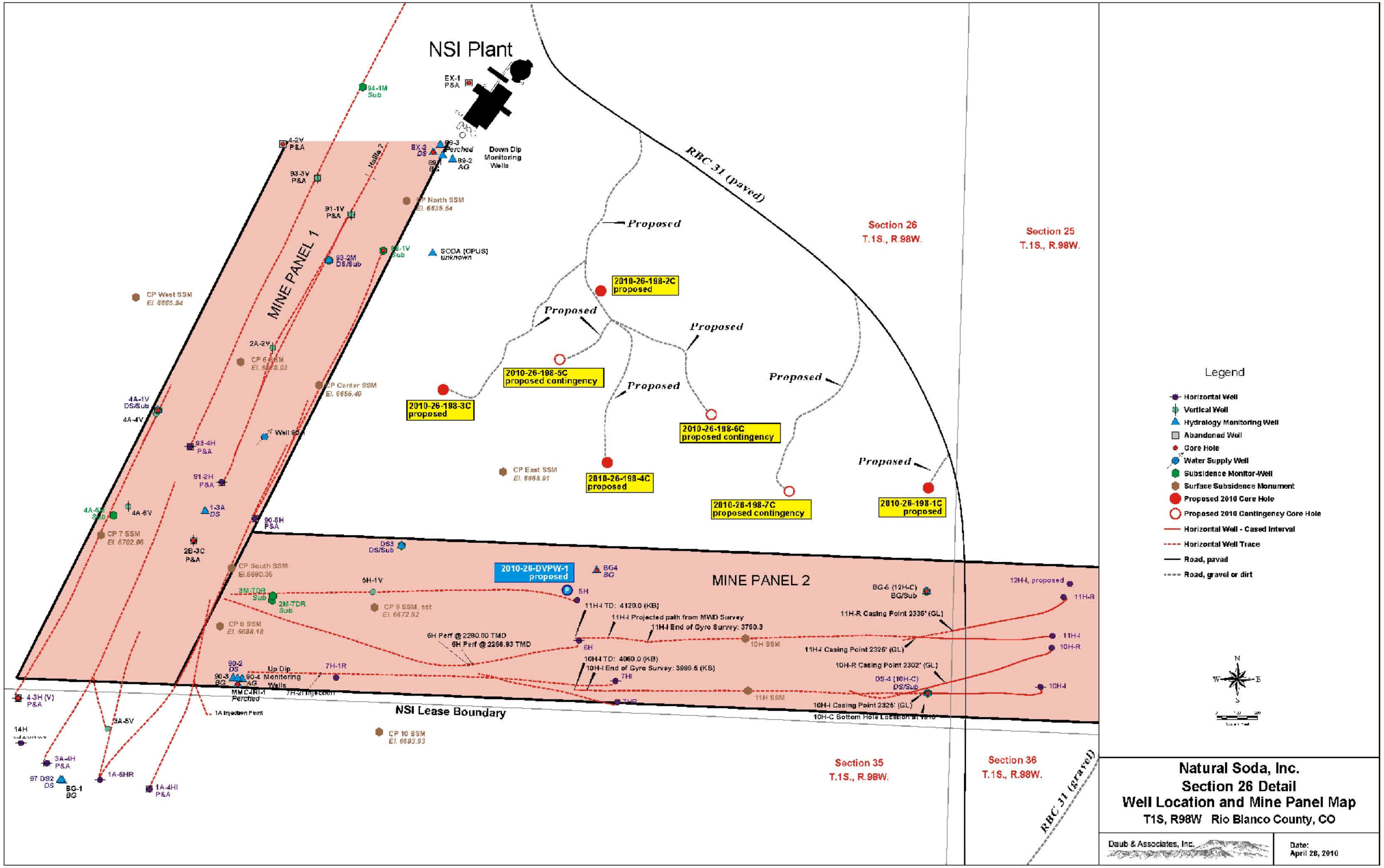

Figure 6-6. Well location and Mine Panel Map.

6.4.8. Drilling, Completion and Abandonment Details – Stratiform Saline Minerals

6.4.8.1. Well Drilling Permitting Procedure

As additional mining or monitoring wells are required, well permit applications will be submitted for approval to the Authorized Officer. For wells off the lease, such as may be needed to recover the resource along the southern lease boundary, a BLM Right of Way (ROW) application is also required. The Authorized Officer will review and approve, with potential modifications, the APD within 30 days of receipt. The Authorized Officer can verbally approve changes to an approved APD as long as the change conforms to the Mine Plan. The loss of a well, or providing for the personnel safety, may require immediate corrective action. Written Sundry Notices will follow in a timely manner for all changes to the APD. The Authorized Officer will be notified 24 hours prior to commencement of drilling and geophysical logging operations.

6.4.8.2. Horizontal and Vertical Well Drilling and Completion

Surface casing will be of a size, weight, grade and setting depth to sufficiently support the wellhead stack. Once in place, the surface casing must maintain a seal while drilling the well with pressurized drilling fluids.

Surface casing will be set and cemented using a volume of cement calculated to fill the annulus from the setting depth to the surface. Any un-cemented annulus near the surface will be topped off using cement.

Two non-specific examples of surface casing and cementing specifications follow:

Example 1	Example 2
13 3/8" OD	9 5/8" OD
54.4 lb/ft	36 lb/ft
J-55, ST & C	J-55, ST & C
Setting depth 80 feet	Setting depth 80 feet
18" open hole	12 ¼" open hole
11.3 bbl + 5.6 bbl excess cement	4.5 bbl + 2.3 bbl excess cement

A diverter and/or Blowout Preventer (BOP) may be installed on top of the surface casing once the surface casing is cemented in place. The working pressure of this device will be greater than 1.0 times the True Vertical Depth (TVD) of the well.

Production casing will be sized to facilitate successful completion and operation of the well. Casing will be designed using the following safety factors:

Tensile Strength	1.6
Burst	1.25
Collapse	1.25
Compressive Strength	1.25

Two examples of production casing follow:

Example 1	Example 2
9 5/8” OD	7.625” OD
36 lb/ft	26.4 lb/ft
J-55, LT & C	J-55, LT & C
12.25” open hole	9.875” open hole

The production casing shoe will be set just above the top of the Boies Bed. Casing setting depths may vary based on drilling conditions and/or mining interval thickness, but BLM approval is required regardless.

NSI will cement the production casing in place from the shoe, and/or DV tool to the surface. Cement can range from light weight to nitrogen foam cement slurries. A cement bond log (CBL) will be run to confirm at least 100 feet of “good” annular cement bond below the B-Groove Aquifer. This minimum requirement will properly support the casing and isolate the B-Groove Aquifer from the mining activity. To accommodate for lost cement, an excess of 30-50% will be used unless nitrogen foam cement is used. Above the B-Groove Aquifer the uncemented well bore will be filled with high viscosity cement or a mix of bentonite mud and cement. Cementing material will adequately prevent aquifer co-mingling. The casing will be cemented above the Perched Aquifer and topped off, as necessary, by pouring or pumping cement down the annulus from the surface.

Adequate wait-on-cement time shall be observed for all cementing operations to achieve a minimum of 500 psi compressive strength. The wireline tool for establishing cement bond will be a CBL with transit time, variable density log (VDL), gamma ray (GR), casing collar locator (CCL) and amplitude or pipe energy (measured in mv), or other equivalent tools such as a CAST-F or CET. Reasonable attempts will be made to record the cement bond using a CBL tool, starting from the lowest practical point reached and, extending to the top of the cement. Logging for an additional 100 feet of free pipe will be recorded. Recording less than the above minimums will require the Authorized Officer to waiver the requirements. A Sundry Notice will follow to confirm verbal approvals.

Directionally drilled horizontal boreholes will extend along or within the floor of the Upper or Lower Boies Bed. A casing liner will be installed and attached to the production casing and extend to the end of the horizontally drilled well section. This section of injection liner will be suspended by a liner hanger and not cemented in place. As the cavity is mined the injection point will be relocated by plugging and perforating the casing at designated locations. This retreat mining method will ensure the cavity is developed symmetrically along the length of the injection liner. Two typical suspended casing liner specifications follow:

Example 1	**Example 2**
7" OD	**5" or 5 ½" OD**
23 lb/ft	**Casing weight may vary**
J-55, SFJ	**J-55, SFJ**

Casing liners will be sized based on well flow requirements, bit size used to drill the open hole, availability and price.

6.4.8.3. Drilling Problems and Contingency Plans

Casing Modifications

If production casing run in the hole is unable to reach into the top of the Boies Bed, due to poor well bore conditions, the production casing may be cemented in place. A casing liner will then be set to the top of the Boies Bed using a liner hanger and cemented in place. Casing design for the wells may change based upon availability at the time of drilling, well problems, drill hole conditions and resource thickness. The authorized officer, or his designee, will verbally approve any changes to the previously approved APD, followed by a written Sundry Notice.

Well Bore Plug Back

During any drilling operation, if the Boies Bed roof is penetrated at an unacceptable angle, the well bore may be plugged back with cement to an acceptable kick-off point for re-drilling. The plug back is a drilling requirement, not a mining condition.

Circulation/Cementation

Lost circulation is problematic in the central part of the Piceance Creek Basin, often compromising well bore cementing results. Cementing results may be enhanced by the use of DV tools, cement baskets, centralizers, scratchers and/or other cement tools and modified cement slurries to ensure the proper encasement of the production casing. NSI will verify the annular cement. If NSI establishes that cementing did not satisfy the minimum requirements, the Authorized Officer will be contacted to evaluate a waiver of minimum requirements and cement plans. NSI is committed to protection of all USDW aquifers from the mining interval. When possible, shooting and cement squeezing will be utilized for this purpose. Experience has shown that when the cement used to isolate the well bore from the aquifers is brought to surface during the primary cementing job, the column of cement on the backside will fall back. In this case, a cement mixture will be pumped or poured down the backside until its level can be maintained to surface.

Orientation

The orientation of the horizontal well pair may change as production, lease, subsurface, mechanical, and technological knowledge advances.

Removal of Casing Liner

If while attempting to retrieve the suspended casing liner, the liner cannot be pulled and attempts to free it are unsuccessful, the liner may be cut, recovered and reused if it is not compromised. If other methods are necessary, approval will be requested from the Authorized Officer.

Length of Horizontal Hole

To quantify the downhole directional system data, the bit will be allowed to drill past a vertical target well approximately 50 feet. This allows the monitor well drilling package to be positioned directly under the vertical intercept of the recovery well. The distance from recovery wells will be variable and may be up to 3500 feet. Cavity length is a function of the horizontal drilling technology and downhole conditions. Cavities in excess of 3500 feet are achievable using the current drilling equipment. If lengths greater than the distance previously granted in the Sundry Notice are advantageous and achievable, permission may be requested from the Authorized Officer to continue.

Fishing Operations

If the drilling assembly or borehole equipment becomes stuck downhole and recovery efforts are unsuccessful, cementing and side tracking will be utilized.

Short Radius Drilling

The technique of short radius drilling may be incorporated to connect the well bore to existing cavities. This method of drilling employs a short radius drilling technique, through which a nozzle and hose are directed to change from vertical to horizontal direction. The nozzle employs high-pressure water to drill through the horizontal formation. Vertical wells may be drilled to inject and recover production fluids.

6.4.8.4. Well Abandonment

Reporting Requirements

A "Notice of Intent to Abandon" will be submitted by NSI to the Authorized Officer before abandonment of any well. The notice will contain an "as-built" downhole diagram of the well and will describe any changes from the approved abandonment/plugging procedures. The Authorized Officer (BLM and/or EPA) will review and approve, or approve with modifications, the notice within 30 calendar days of receipt. A Sundry Notice will be submitted for both the "Intent to" and "Subsequent" notice.

Production Well Abandonment Procedure

Class III UIC well plugging and abandonment procedures are outlined in the EPA's UIC document. Plugging and abandonment of these wells will take place once it has been determined that there shall be no potential further use of a well, either for mining, testing, monitoring, or other purpose. Immediately prior to plugging and abandoning a cavity and associated wells, any tubing, liner or packer system located in the casing above the Dissolution Surface shall be removed from the casing. The plugging and abandonment plan for the wellbore submitted by NSI and revised by the EPA, consists of either cementing the wellbore above the bridge plug to the surface with cement or setting five (5) plugs with the following specifications: The wellbore will be conditioned for plugging and abandonment by displacing the nahcolite brine in the wellbore with either bentonite, plugging gel, or other suitable fluid (approved by the Director upon submittal of the notice to plug). The operator shall run into the wellbore with a tubing string to the bottom of the casing. A cast iron bridge plug (CIBP) shall be set at the bottom of the casing. After the bridge plug is set in the conditioned hole, a cement plug to the surface shall be placed or the individual plugs shall be sequentially set by using one or more of the approved methods described in 40 CFR § 146.10. If the casing is not cemented to the surface from the top of the bridge plug, the cement plugs shall be set at points in the wellbore required to prevent migration of fluid within the casing. The exact depths for cement plugs are not specified , but the anticipated locations for setting cement plugs are:

Plug #1: The lowest plug shall span the entire Dissolution Surface aquifer from the CIBP, the water producing zone plus fifty feet above.

Plug #2: The second plug shall begin fifty feet below the water producing zone of the B-Groove aquifer, bridge the entire aquifer and extend fifty feet above the aquifer.

Plug #3: The third plug shall begin fifty feet below the water producing zone of the A-Groove Aquifer, bridge the entire aquifer and extend fifty feet above.

Plug #4: The forth plug shall begin fifty feet below the Perched Aquifer, bridge the entire aquifer and extend fifty feet above.

Plug #5: The final plug shall be from one hundred sixty feet below ground surface to ground surface. A 9.2 ppg plugging gel, Bentonite mud, or cement shall be placed between each plug.

The casing will be cut off below grade, a P&A marker with well data will be installed and reclamation activities shall commence per BLM specifications.

6.5. Process Monitoring

Process monitoring includes continuous monitoring equipment to record flow rate, pressure and temperature of the injection and recovery fluids. Pressure and temperature measurements consist of local (near wellhead) and remote (at the plant control room) sources of data. Flow data is recorded by the distributed control system (DCS), which captures the injection and well flow rate, and the flow data from the pregnant liquor tank. Pressure and temperature are monitored continuously, with four-hour maximum/minimum and average readings printed for daily records. Monthly and quarterly reports summarize the daily readings. The following is a list of process control monitoring items:

- Initial water quality of the injection fluids for major ions, TDS, pH, specific conductivity and specific gravity, and whenever a new source of supply water is utilized. A flow line tap is provided for obtaining representative samples of the injection/recovery fluids.

- A pressure indicator is located near each well head. Continuous readings are recorded. In addition, a tap is provided near each well head for local pressure readings.

- A flow meter is installed on each well. Based on historical data and a potential for inaccurate recovery readings (due to gas bubbles), the injection flows are utilized to monitor flow to cavities; total flow from the pregnant liquor tank is utilized for recovery data. To differentiate pregnant liquor flow from each cavity, the flow will be recorded from each individual cavity on a periodic basis.

- Downhole submerged pressure transmitters are installed in Dissolution Surface monitoring wells within the active mining panel. Data from these transmitters are trended in the Process Control Room to provide operating personnel with an indication of any pressure imbalances between the mining cavity and the Dissolution Surface so corrective actions can be taken.

- Temperature sensors monitor the temperature of injected and produced fluids.

- The specific gravity of the produced and injected fluid is monitored at least weekly. Sodium bicarbonate analyses, in grams/liter, are obtained from injection and recovery solutions at least once per week to determine production from each cavity.

- The maximum allowable injection pressure (MAIP) is limited to 300 psig, as measured at the surface (UIC, Part II.C.2).

A comprehensive monitoring program for monitoring surface and groundwater, subsidence and other environmental factors may be found in the Comprehensive Monitoring Plan (submitted under separate cover).

6.6. RD&D Plan – Deep Vertical Production Well (DVPW)

6.6.1. Introduction

NSI currently produces sodium bicarbonate by the horizontal solution mining of relatively concentrated bedded nahcolite in the upper portion of the Saline Zone, known as the ‘Upper Salt’. NSI is also evaluating alternative, deeper sodium resources and processes, in an attempt to better understand and maximize resource recovery in deeper intervals of the Saline Zone. As a part of this effort, NSI proposes to drill a Research Development & Demonstration (RD&D) Deep Vertical Production Well (DVPW) in 2010.

The experimental test well will be drilled within the boundaries of NSI’s sodium lease on an existing pad, thereby minimizing disturbed areas and maximize the use of preexisting facilities, area roads and drill pads. Operational life of the DVPW is anticipated to be up to 5 years.

The DVPW will test the viability of vertical dissolution of nahcolite (sodium bicarbonate) in the lower part of the Saline Zone through the use of a relatively low temperature and pressure injectate. Heated water (barren liquor) will be injected into the mining interval, resulting in the dissolution of soluble saline minerals. This fluid will recirculate, in a closed loop, between the mining interval and the surface. This solution will be reheated and reinjected, as required, until optimal nahcolite saturation is achieved. Once saturated, the “pregnant liquor” will be pumped out, sent to the pregnant liquor tank, at the plant, and processed to produce sodium bicarbonate. The DVPW will use NSI’s existing processes, including current injectate, operating temperatures, pressures and monitoring systems.

6.6.2. Objectives

The primary objective of the DVPW will be to demonstrate the future commercial viability of vertical solution mining of thinly bedded and disseminated sodium minerals from the deeper portion of the Saline Zone beneath the NSI lease. This will allow NSI to maximize resource recovery and hopefully prove commercial viability utilizing this methodology.

This experimental well program will collect and evaluate data on technical issues that pertain to future commercial viability. Key objectives include:

- To demonstrate that disseminated and thinly bedded sodium minerals can be effectively solution mined in vertical intervals. Disseminated nahcolite occurs as nodules, aggregates and individual crystals within an oil shale matrix and may constitute on average approximately 25 percent of the rock volume.

- To determine the operational parameters, such as temperatures, pressures, and brine flow rates, which are necessary to extract disseminated and thinly bedded nahcolite.

- To empirically evaluate the growth rate, growth characteristics and ultimate size of the solution mined interval, as well as the evaluation of data collection methods.

- To determine the composition of production fluid as a function of recirculation time and evaluate fluid characteristics for processing.

- To collect data and evaluate these data concerning the development of the mined interval.

6.6.3. Pad Location and Mining Interval

The DVPW will be located in the SW ¼ of the SE ¼ of Section 26, Township 1 South, Range 98 West, 6th Principal Median in Rio Blanco County, Colorado. This experimental well will be located on a portion of the pre-existing 5H well pad (Figure 6-8). The DVPW will require an area of approximately 150 feet by 150 feet in the northern portion of the relatively large 5H pad. An existing pit near the NW portion of the 5H pad will also be reused. Interim reclamation of other portions of the 5H pad may proceed as scheduled.

The proposed solution mining interval for the DVPW is located within the lower portion of the Saline Zone of the Parachute Creek Member of the Green River Formation. The proposed solution mining interval is located below the Lower Salt (Figure 6-9) to provide a sufficient buffer zone between the mining interval and aquifers at more shallow depths.

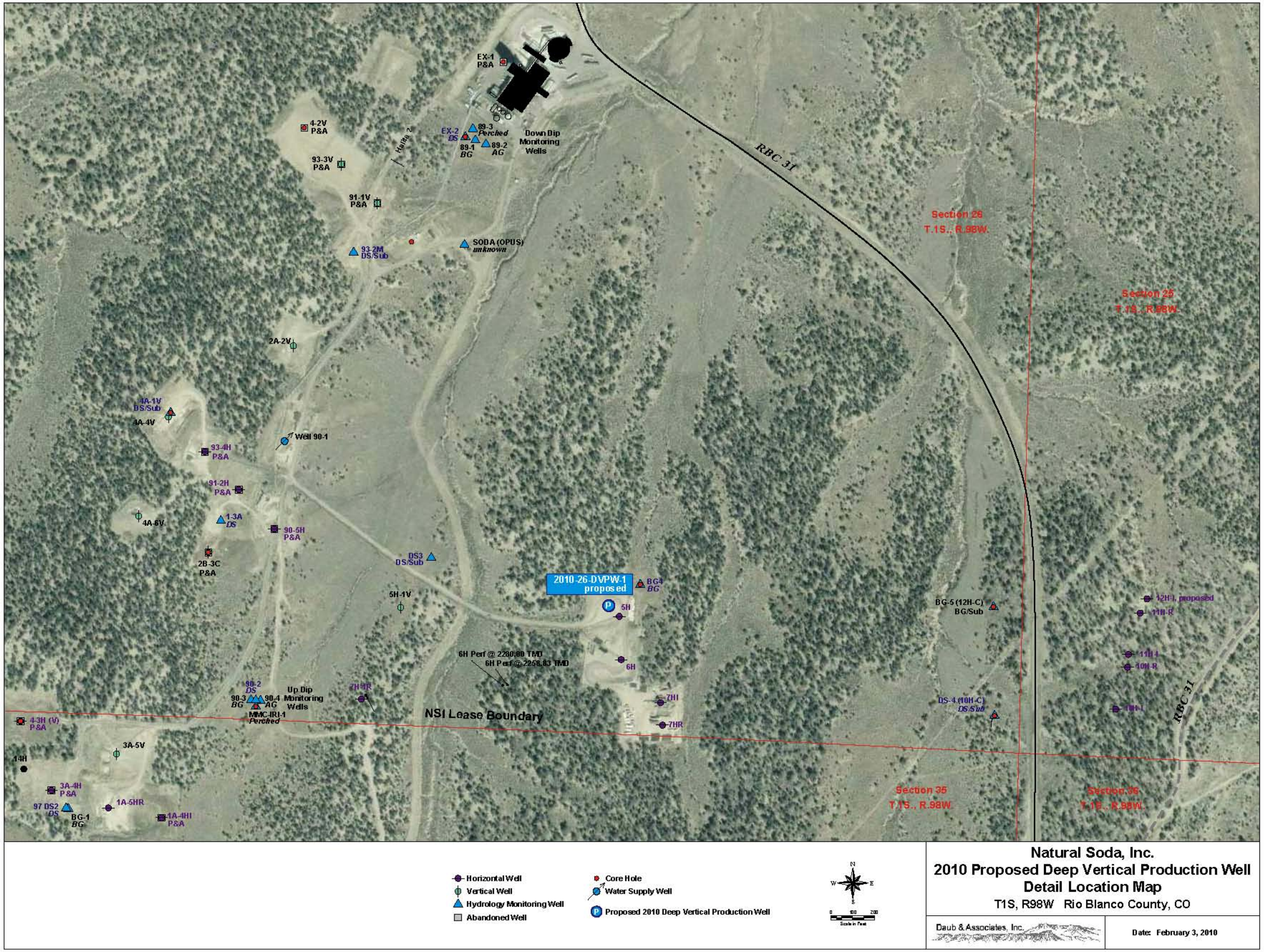

Figure 6-8. 2010 Proposed DVPW Location Map.

6.6.5. Mining Activity Monitoring

An accurate understanding of the on going changes to mass balance is vital to achieving the stated objectives of the DVPW. Key to that understanding will be NSI's operational monitoring plan for the DVPW.

Mining/process monitoring will include continuous monitoring equipment to record flow rates, pressures and temperatures of the injection and recovery fluids. Pressure and temperature measurement provide local (near wellhead) and remote (at the plant control room) sources of data. Flow data will be recorded by the distributed control system (DCS), which captures the injection and well flow rate, and the flow data from the pregnant liquor tank. Pressures and temperatures will be monitored continuously. Four hour maximum/minimum and average readings will be printed for daily records. Quarterly reports will summarize daily readings. The following is a list of process control monitoring items:

A. Initial water quality of the injection fluids (barren liquor) will be performed for major ions, TDS, pH, specific conductivity and specific gravity, and whenever a new source of supply water is utilized. A flow line tap will be provided for obtaining representative samples of the injection/recovery fluids.

B. A pressure indicator will be located near the well head. Continuous readings will be recorded to monitor tubing/long string casing pressure; this also assists in evaluating mechanical integrity. In addition, a tap will be provided near each well head for a local pressure gauge.

C. A flow meter will be installed on the well. Based on historical data and inaccurate recovery readings (due to entrained gas bubbles), the injection flows will be utilized to monitor flow to mined intervals; total flow from the pregnant liquor tank will be utilized for recovery data.

D. Temperature sensors will monitor the temperatures of injected and produced fluids.

E. The specific gravity of the produced and injected fluid is monitored at least weekly. Operators in the plant obtain samples at a minimum of once per shift (2 per day) during normal operating periods, and measure the specific gravity of both the injected and recovered liquors with a hydrometer. Sodium bicarbonate analyses, in grams/liter, are obtained from injection and recovery solutions at least once per week to determine production from each mined interval.

Existing Dissolution Surface monitoring wells will be used to monitor the Dissolution Surface Aquifer. The operational life of the DVPW is anticipated to be approximately 5 years. Monitoring plans will be in place and updated as necessary for the duration of DVPW operations.

Mechanical Integrity Testing (MIT)

MIT will be run in conjunction with initial injection activities and at least once every five (5) years for the life of the well. The EPA will be notified prior to running the initial Cement Bond Log and Mechanical Integrity Testing.

MIT Part 1 (40 CFR §146.8(a)(1)), requires pressure testing to be performed on the casing per EPA Guidance Document 39. If a pressure drop of more than 10% (300 psig minimum test pressure) is noted over a 30 minute interval then MIT Part II will be initiated.

MIT Part II (40 CFR §146.8(a)(2)), requires temperature testing for micro annuli in the casing cement. The basic test involves running a baseline temperature log, injecting 120º F injection liquor for at least 72 hours to raise the formation temperature and then shutting in the well. At least three temperature logs (cool down passes) run over an eight (8) hour period after the well has been shut-in are required. The three temperature logs will be compared to the baseline temperature log.

6.6.6. Well Abandonment and Pad Reclamation

If the DVPW is successful, NSI may consider commercial mining opportunities using the vertical well design or a variation of this design/concept utilizing vertical, inclined, deviated and/or horizontal wells. The DVPW may then be used for commercial production. Plugging and abandonment will occur if the well is deemed unusable for future use as a monitor or production well. This plugging and abandonment plan may be modified based on site conditions at the time of abandonment.

Prior to plugging and abandoning the DVPW, the two 4.5 inch production and injection tubing strings (2850 feet and 2350 feet) set inside the two 7.0 inch casing strings will be removed from the wellbore. A bridge plug may be set near the top of the solution mined interval. The residual brine will be left in the solution mined interval and will stabilize and support the mined interval.

NSI will likely cement the well to surface after borehole preparation is complete. As a minimum, the following plugs will be required (per NSI EPA UIC Class III Area Permit): 1) a CIBP will be placed at the base of the production casing; 2) cement the entire DS aquifer interval plus fifty feet above; 3) the entire B-Groove Aquifer interval must be plugged, and the plug must extend fifty feet above and below the aquifer; 4) the entire A-Groove Aquifer interval must be plugged, and the plug must extend fifty feet above and below the aquifer; and 5) the final plug must extend from the surface to 165' below ground level. The intervals between the cement plugs will be filled with a bentonite based plugging mud and/or cement. Other cement plugs or revised plugging procedures may be required based on CBL analyses and casing recovery results. Any remaining casing will be cut off and removed to a depth of 2 feet below grade. An appropriate surface location marker will be installed at grade. The well abandonment will conform to 40CFR §146.10 and BLM requirements.

Reclamation efforts shall commence at such time as the DVPW pad area and any remaining portions of the 5H pad and access roads are no longer needed. These areas will be reclaimed per BLM guidelines and schedules. Section 8 contains information concerning reclamation plans and objectives.

6.7. Comprehensive Monitoring Plan

NSI's Comprehensive Monitoring Plan (submitted under separate cover) is a stand alone document which was prepared for the Bureau of Land Management (BLM), Environmental Protection Agency (EPA) and the Colorado Division of Reclamation, Mining and Safety (DRMS) pursuant to BLM, EPA, and DRMS requirements concerning NSI's commercial-scale nahcolite solution mining project in Rio Blanco County Colorado.

NSI operates, monitors and reports in accordance with the most current stipulations of the BLM's Record of Decision (ROD), the EPA's Area Underground Injection Control Permit (UIC) CO30358-00000, the DRMS Permit M-1983-194, and any subsequent conditions of approval and required mitigation. NSI submits routine reports to the BLM, EPA and DRMS. Should there be a discrepancy between the ROD, UIC or DRMS Permit ("Permits") and this Monitoring Plan, the Permit requirements will take precedence.

The BLM, EPA, and DRMS mandated monitoring programs are comprehensive, intended to provide the agencies with a means of determining NSI's surface and subsurface environmental impacts. The monitoring plan is designed to enable detection and/or evaluation of biologic and hydrologic impacts.

The Permits were approved for the operational life of the project. The regulatory agencies and NSI continue to proceed on a phased approach based upon the Mine Plan, which provides detailed plans, current operations, and anticipated operations anticipated for the next five to ten years and general plans for long term. The project will continue operations if monitoring results do not indicate significant negative impacts.

NSI's Comprehensive Monitoring Plan will be updated periodically to remain current with respect to areas being mined. An updated Comprehensive Monitoring Plan will be submitted to the appropriate agency for review and approval prior to implementation.

6.8. Affected Acreage

Construction and operations at the solution mine site are anticipated to ultimately affect a maximum of 260 total acres of land. NSI's 2009 annual report indicated 14.2 acres of disturbed land for the process area and 37.4 acres of disturbed land in the well field for a total of 51.6 acres of disturbed land. Disturbed areas will be reclaimed in a timely manner and consistent with the reclamation program. The reclamation program is discussed in more detail in Section 8.

6.9. Rock Mechanics and Subsidence

6.9.1. Rock Mechanics

In addition to Agapito Associates, Inc. report dated 1995, many core holes and other applicable rock mechanics work has been conducted in the Piceance Creek Basin. This data indicates that NSI's mining concept continues to be valid.

6.9.2. Boies Bed Mining Evaluation

High-extraction mining separated by barrier pillars is recommended to control the potential caving above the mined interval and to minimize surface subsidence. Forty-percent extraction of the available nahcolite resources in and above the Boies Bed and below the DS within such panels is possible without adverse impact on the minability of the "Mahogany" oil shale or the upper aquifers per Appendix A. Based on this and other data and future mining experience, recovery of more than 40% of the available nahcolite may be possible without damage to the aquifers or oil shale minability.

6.9.3. Solution Mining Groundwater Effects

For more than 17 years Natural Soda, Inc. has tested and established a credible baseline for groundwater quality information on four aquifer systems in the Piceance

Creek Basin. In 1995 the operation incurred a variance in the A-groove Aquifer water quality in the 90-1 well, directly above the mining zone. Up to that time, the established solution mining technology was to inject barren brine into the cavity under pressure, thereby forcing saturated brine to surface for processing. An anomaly in the pressurized cavity allowed mining fluid to infiltrate a portion of the A-groove Aquifer directly above the mining zone. This variance was corrected by developing the current mining technology of installing submersible downhole pumps in the recovery wells and maintaining mining cavity pressures in equilibrium with the Dissolution Surface. The localized reduction of water quality in the A-Groove Aquifer was remediated by utilizing the 90-1 well as a water supply well for the Processing Plant, thereby consuming this lower quality fluid. The 90-1 well parameters are approaching baseline conditions, and no impacts from this variance were seen up-dip or down-dip from this well.

Long term pumping of the A-Groove Aquifer (1990-2010) indicates hydrologic communication between the A and B-Groove Aquifers, but not upward to the Perched Aquifer or downward to the DS Aquifer. The DS Aquifer is the only aquifer within the zone of possible significant caving or subsidence resulting from Boies Bed solution mining. The DS Aquifer is recognized by the EPA as a non-protected, aquifer due to its poor water quality and is not a USDW.

Although the A-Groove Aquifer is separated from the B-Groove Aquifer by a leaky, semi-confining layer commonly referred to as the Mahogany Zone, at the NSI and U.S. Bureau of Mines Horse Draw Facilities, aquifer testing has determined that significant communication between upper (A-Groove) and lower (B-Groove) aquifers does exist. It should also be noted that the potentiometric head of the upper three aquifers is historically higher than that of the DS Aquifer at all NSI monitoring locations. Consequently in the long term, should communication between the upper aquifers be caused by mining-induced subsidence or fractures, the result would be that additional water could flow from the upper aquifers to the lower quality DS Aquifer. The use of submersible pumps since May of 1995 has subsequently decreased the potentiometric head in the DS Aquifer. NSI controls cavity pressure by balancing solution injection and recovery. Following mining, potentiometric levels are expected to recover to historic levels. Extensive monitoring will be conducted to verify that effects are limited to DS Aquifer wells, additional details may be found in the Comprehensive Monitoring Plan (submitted under separate cover).

In addition to the historic potentiometric head differential, it has been concluded that any groundwater effects would be minimal as saline or high-density water will remain at the bottom of the aquifer. In the long term, the high-density water in the caved rock and rubble-filled Boies Bed cavity will stagnate; thus, this will not significantly alter the groundwater quality in the overlying aquifers. As previously described, local effects on groundwater (found within the three protected aquifers) resulting from subsidence should be minimal. No surface subsidence has been detected through 2009. Furthermore, it is doubtful that any effects would be observed on a regional basis. Imperceptible changes may occur in the three protected aquifers due to the caving and subsidence induced by solution mining.

Significant additional hydrological knowledge has been gained by the monitoring system. No mining effects have been detected on the A-Groove, B-Grooves or Perched monitoring wells.

6.9.4. Surface Subsidence

The Environmental Impact Statement (EIS) estimate of potential surface subsidence was less than one foot. A current estimate of surface subsidence is less than 0.6 feet. Surface subsidence will be uniform in aerial extent over the area to be mined. Subsidence expressed at surface of this type will not hinder post-mining land use as range/wildlife habitat and will be uniform (e.g., a gradual sag). The surface expression of subsidence should be undetectable except by survey methods. In other words, no appreciable changes in surface topography will occur.

6.10. Engineering Standards

The plant facilities, associated evaporation ponds, load out unit, access road, utility pipelines and power lines were designed and constructed under the direction of professional engineers. Currently planned plant improvements and expansions will be designed and constructed under the direction of a professional engineer. Although it is not currently anticipated, should new facilities be required, they too will be designed and constructed under the direction of a professional engineer.

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NATURAL SODA

2010 Mine Plan
Volume 4, Section 6A
Appendix

Prepared for:

Natural Soda, Inc.
Piceance Creek Basin
Rio Blanco County, Colorado

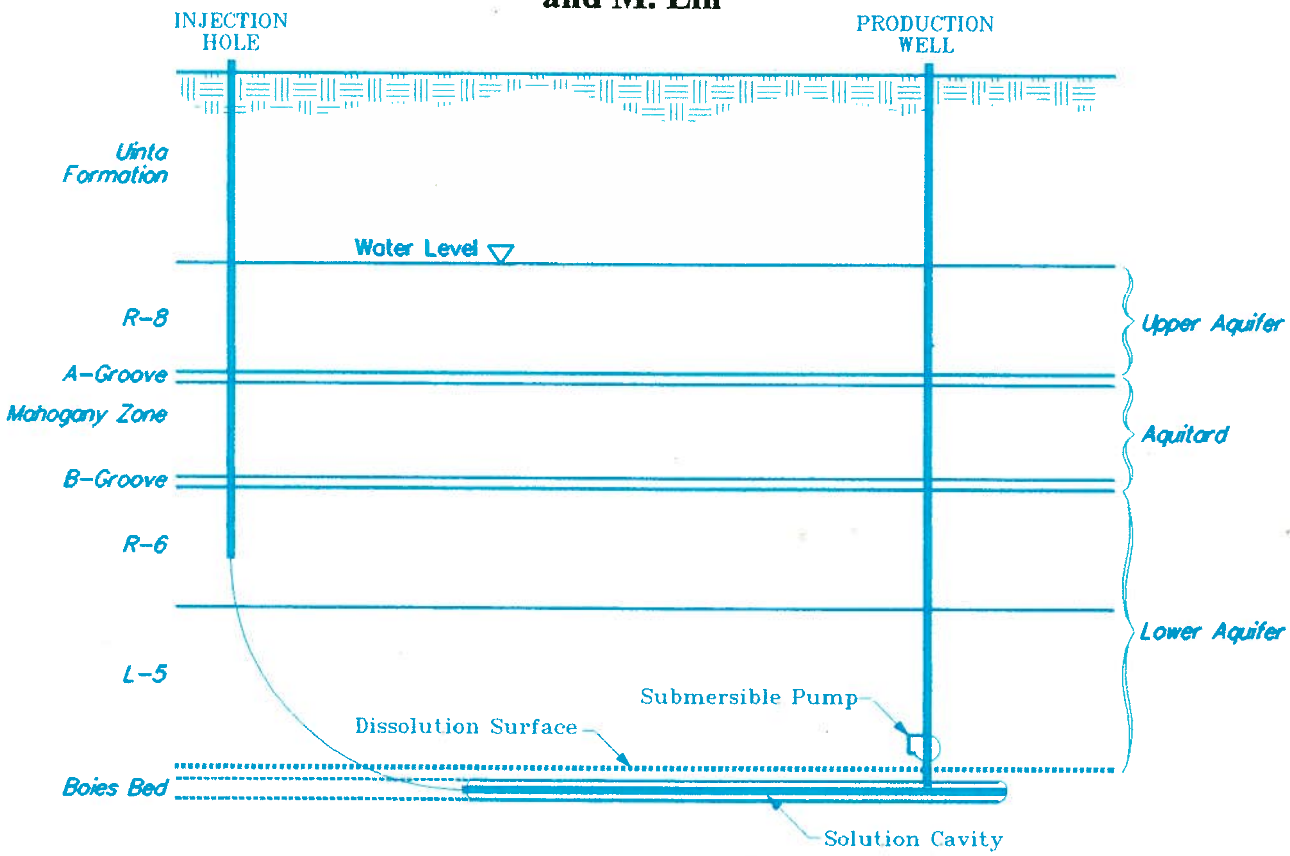
AN EVALUATION OF IMPACTS OF HIGH-EXTRACTION SOLUTION MINING ON OVERLYING AQUIFERS AND MINABILITY OF OIL SHALE

prepared for

White River Nahcolite, Inc.
Rifle, Colorado

by

M. P. Hardy
and M. Lin



November 22, 1995

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AN EVALUATION OF IMPACTS OF HIGH-EXTRACTION SOLUTION MINING ON OVERLYING AQUIFERS AND MINABILITY OF OIL SHALE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This report results from discussions relating to the long-range plan for solution mining of the nahcolite present in the Boies Bed at the White River Nahcolite, Inc. leases at the Wolf Ridge site. Specifically, the changed operating conditions within the caverns resulting from the use of submersible pumps to control leakage provokes reassessment of the impact of reduced cavern fluid pressures on stability of cavern and ultimate cavern size. A quick review of the controlling permit requirements — impact on overlying potable water and the vulnerability of overlying oil shale — indicated that the new operating procedures allowed a significant increase in recoverable resource because collapse of a cavern would not result in leakage to the groundwater system and would have no impact on the minability of the overlying oil shale of economic interest.

This report details the rock mechanics aspects and potential impacts of mining as much of the nahcolite resource in the Boies Bed and overlying strata as possible within the constraints of the mine permit using the new solution mining technique. The report is structured to first detail the proposed mine plan and available nahcolite resource. The third section details possible cavern shapes associated with high-extraction solution mining. This takes into account the experience from partial mining of the first four caverns, the variability in the grade of resource, the potential for unrecoverable resource because of halite intrusion and the uncertainty of the solution mining process and, hence, the inconsistency of cavern shape. The fourth section addresses case studies of mining impact on overlying groundwater hydrology and minability of overlying strata. Criteria established in the mining literature are used as the basis for evaluation of high-extraction solution mining. Section 5.0 summarizes the analytical evaluation of the proposed mine plan. The analysis considers extraction of 40% of the available nahcolite in and above the Boies Bed in panels 800-ft wide. Panels would be separated by 200-ft barrier pillars. The analysis includes the potential for rubblization of the overlying strata to fill the void created by solution mining, and yield and deformation of the overlying strata. The impact of solution mining on the aquitard between the mining horizon and the B-Groove aquifer is assessed. The impact of solution mining on the minability of the high-grade oil shale horizon know as the "Mahogany Zone" is assessed. In addition, the impact of the proposed mine plan and short- and long-term surface subsidence is assessed. In the final section, our conclusions and recommendations are presented.

2.0 MINE PLAN AND AVAILABLE RESOURCE

2.1 Mine Plan

Figure 2-1 shows a schematic cross-section of the solution mining method used at White River Nahcolite, Inc.'s Wolf Ridge property. The new mining technique includes the submersible pump in the production well, thereby, balancing the fluid pressure in the cavern and the fluid pressure in the surrounding rock. The mine plan includes multiple parallel horizontal caverns developed from long horizontal holes. The length of the caverns is controlled by the economics of long horizontal hole drilling and the available resource. Experience to date suggests that horizontal holes of 2000 to 2500 ft are viable. The spacing of the horizontal holes is not defined at this time for the new mining method. In the existing well field, four cavities are located 220-ft apart with the expectation of completing additional caverns between these existing wells for a final cavern spacing of 110 ft. In the new plan, where cavern stability is not a concern, the spacing of wells would be determined to maximize resource recovery and to maintain operational control.

The overall mine plan includes solution mining from a panel of closely spaced horizontal holes with a barrier pillar of unmined material separating the panels. For this evaluation, a panel width of 800 ft and barrier pillar of 200 ft was selected. Long-term mine plans could include panels of different panel orientation to optimize resource recovery or to access resources isolated by property lines and/or resource thinning or replacement. The function of the barrier pillar is to isolate solution mining between panels, to limit surface subsidence, and to promote irregular rubblization above the panel. The irregular rubblization is advantageous in aquifer protection and minability of the overlying strata to promote bulking into the cavern void. An alternate mine layout without barrier pillars would also be successful and would result in gradual and continuous deformation of the overlying strata. This too would be acceptable for aquifer protection and preservation of the minability of the "Mahogany Zone," but would result in higher surface subsidence, and for best results, complete or at least uniform recovery of the nahcolite (no remnant pillars of unmined nahcolite). The former layout, with barrier pillars and hence irregular caving, was preferred because it offers greater flexibility in leaving intermediate pillars and no adverse structural effects of leaving unmined sections because of operational difficulties or halite intrusions.

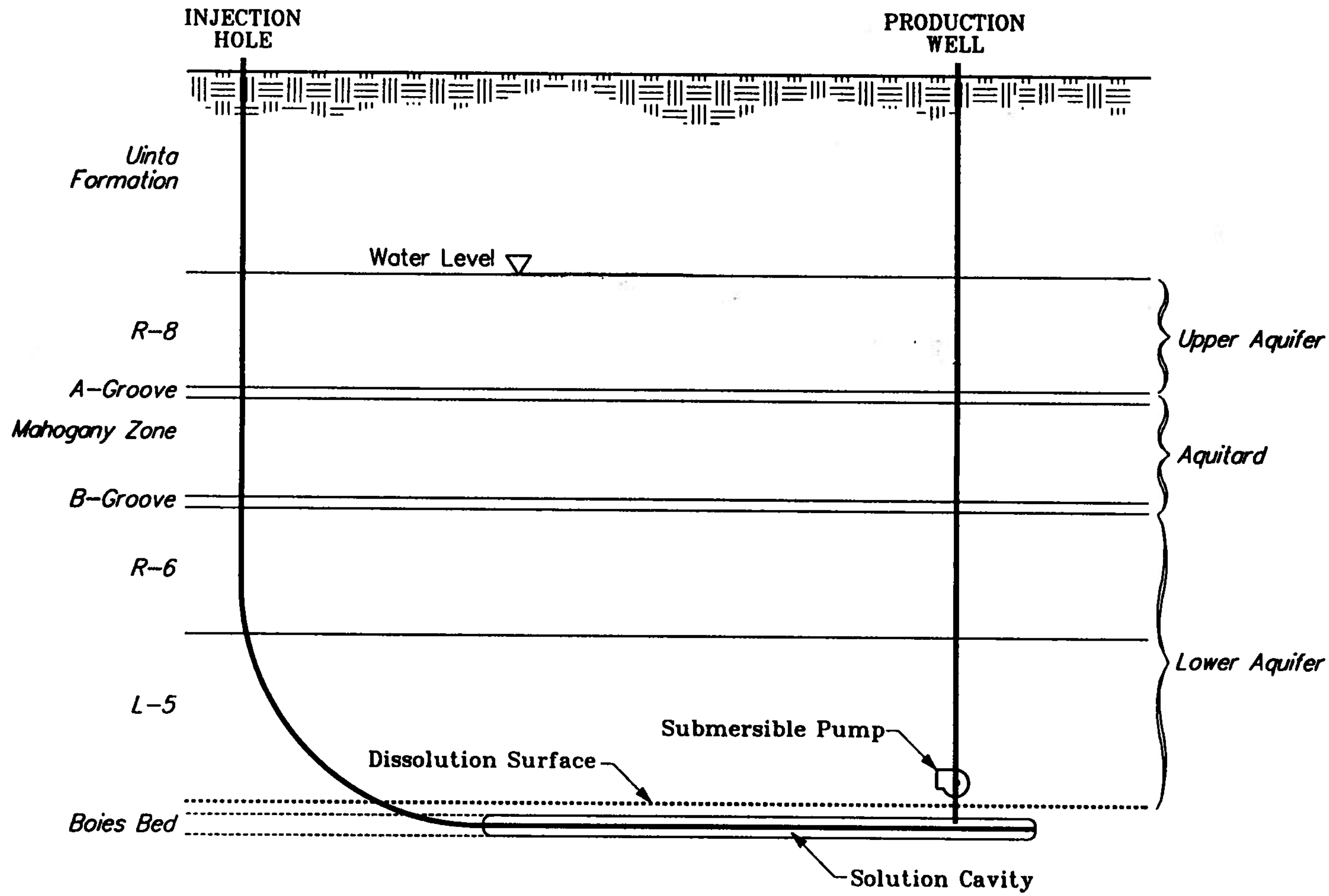


Figure 2-1. Schematic of Solution Mining System

2.2 Available Resource

Figure 2-2 shows the schematic cross-section of the resource of interest. The Boies Bed (L-5A bed) is overlain by the L-5B, -5C and -5E beds. Prior solution mining plans by White River Nahcolite, Inc. have not considered recovery of the resource in the L-5B, -5C and -5E beds as they were relied upon to maintain a barrier between the cavern and overlying waters above the dissolution surface. With the new mining technique, recovery of the resource in the L-5E, -5B and -5C beds is possible. The grade of the L-5B and -5C beds is typically 50% nahcolite, with the L-5E comparable to the Upper Boies Bed (UBB), 80% to 85% nahcolite. Underlying the UBB are the Oil Shale Marker Bed (OSMB) and the Lower Boies Bed (LBB). The grade of the OSMB and LBB are around 50% and 80%, respectively.

Table 2-1 lists the thicknesses of the various beds and the equivalent nahcolite thickness for all holes in and near the first production panel and within the White River Nahcolite, Inc. lease area. The equivalent thickness is calculated by adding together 80% of the height of the L-5E, UBB and LBB and 50% of the height of the L-5B, L-5C and the OSMB. The data sources shown in Table 2-1 are of variable quality. Some of these holes have been cored, others have been cored only in the Boies Bed, and some intervals have been estimated. In general, the Boies Bed is replaced by halite to the north, and to the south, the L-5E, -5C and -5B and Boies beds are progressively truncated by the dissolution surface.

Figure 2-3 shows a two-dimensional contour and a three-dimensional representation of the equivalent nahcolite thickness in the area of interest. At locations EX-1 and EX-2, the equivalent nahcolite thickness is 40 to 45 ft because of good thickness of both the L-5E and the Boies beds. At all other hole locations, the equivalent nahcolite thickness is less than 41 ft. The equivalent thickness was estimated by assuming the nahcolite content of the L-5E, UBB and LBB at 80%, and 50% for the L-5B and -5C and OSMB.

2.3 Overlying Stratigraphy

The overlying stratigraphy of interest in assessing the permit implications of high-extraction solution mining are the location and quality of aquifers and aquitards, and the location of the minable oil shale resource. Figure 2-1 shows the general stratigraphy and definition of the upper and lower aquifers. Table 2-2 lists the typical depths and thicknesses of the overlying strata.

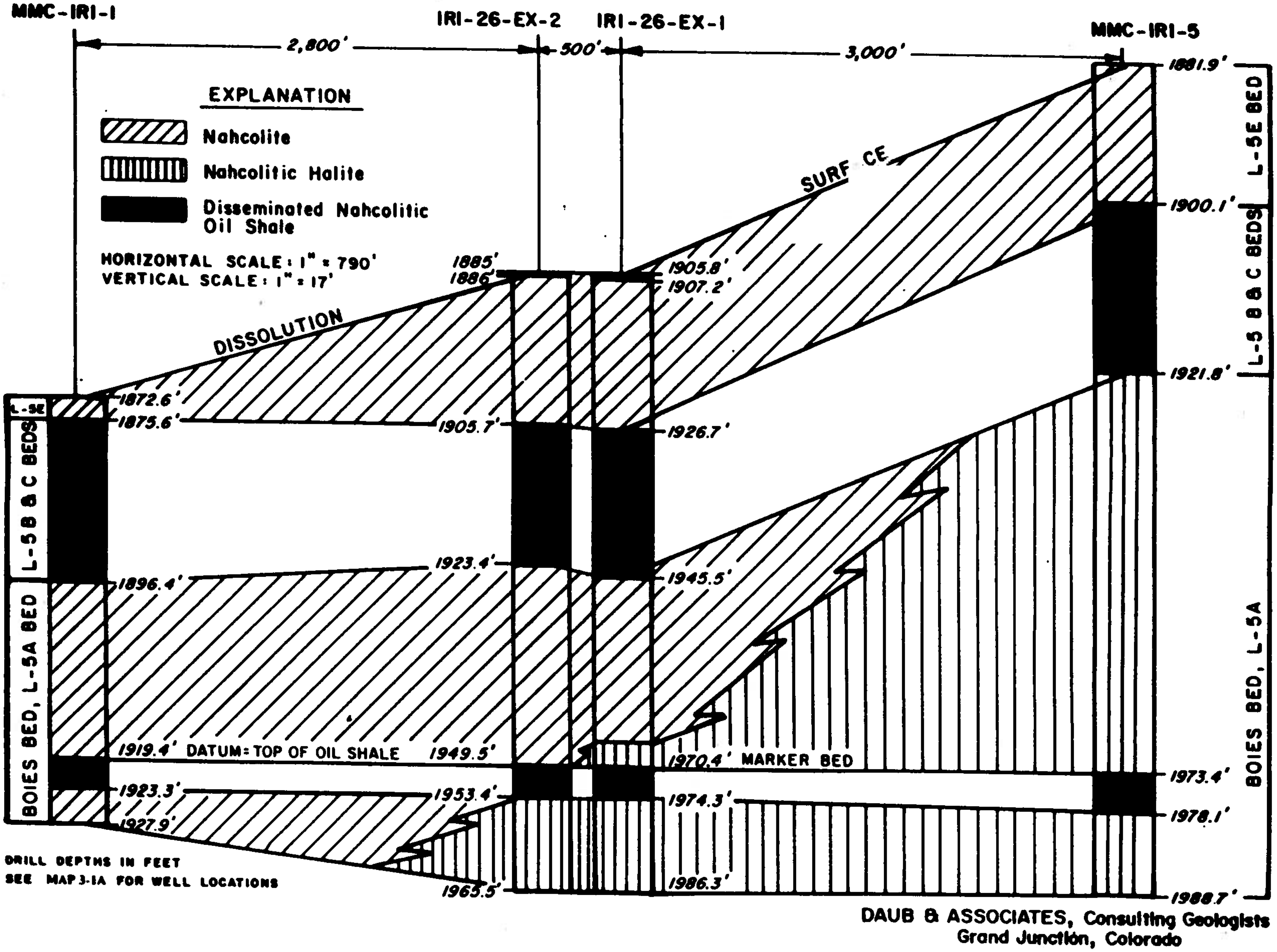


Figure 2-2. Stratigraphic Cross-Section MMC-IRI-1 to MMC-IRI-5, Dissolution Surface to Base of Boies Bed

Table 2-1. Thicknesses of the Various Beds and the Equivalent Nahcolite Thickness

Well	X-Coord.	Y-Coord.	L-5E Thickness (ft)	L-5B&C Thickness (ft)	UBB Thickness (ft)	OSMB Thickness (ft)	LBB Thickness (ft)	Total Thickness (ft)	Equivalent Nahcolite Thickness (ft)	40% Extraction (ft)
IRI-26-EX-1	7,549	7,908	20.0 (A)	19.0 (A)	24.0 (A)	0.0 (B)	0.0(B)	63.0	44.7	17.9
IRI-26-EX-2	7,396	7,432	20.0 (A)	15.0 (A)	27.0 (A)	0.0 (B)	0.0(B)	62.0	45.1	18.0
NATEC-26-88-1	7,163	6,940	11.0 (A)	19.0 (A)	23.0 (A)	4.0 (A)	0.0(B)	57.0	38.7	15.5
IRI-PW-1	3,459	8,827	10.0 (A)	19.0 (A)	22.0 (A)	4.0 (E)	6.0(E)	61.0	41.9	16.8
MMC-IRI-1	6,550	4,780	5.0 (A)	18.0 (A)	24.0 (A)	5.0 (A)	3.0(A)	55.0	37.1	14.8
MMC-IRI-2	2,212	6,070	0.0 (A)	6.0 (A)	25.0 (A)	4.0 (A)	4.0(D)	39.0	28.2	11.3
MMC-IRI-3	3,354	8,842	8.0 (A)	18.0 (A)	25.0 (A)	5.0 (A)	3.0(A)	59.0	40.3	16.1
MMC-IRI-4	8,880	10,410	25.0 (A)	17.0 (A)	0.0 (B)	0.0 (B)	0.0(B)	42.0	28.5	11.4
MMC-IRI-5	8,630	10,650	21.0 (A)	18.0 (A)	0.0 (B)	0.0 (B)	0.0(B)	39.0	25.8	10.3
MMC-IRI-11	14,280	6,310	7.0 (A)	17.0 (A)	12.0 (B)	0.0 (B)	0.0(B)	36.0	23.7	9.5
SKYLINE-1	8,015	9,335	10.0 (A)	22.0 (A)	13.0 (B)	0.0 (B)	0.0(B)	45.0	29.4	11.8
NATEC-26-91-1	6,974	7,079	15.0 (C)	20.0 (C)	20.0 (C)	4.0 (C)	0.0(B)	59.0	40.0	16.0
NATEC-26-91-2	6,899	6,876	10.8 (D)	23.0 (D)	23.0 (A)	5.0 (D)	0.0(B)	61.8	41.0	16.4
WRN-4-1V	6,088	6,133	6.0 (C)	11.5 (C)	26.0 (C)	4.5 (C)	4.0(C)	52.0	36.8	14.7
WRN-4-2V	6,662	7,483	4.0 (C)	28.0 (C)	23.0 (C)	4.0 (C)	0.0(B)	59.0	37.6	15.0
WRN-4-3V	5,442	4,672	0.0 (C)	18.0 (C)	23.0 (C)	6.0 (C)	4.0(C)	51.0	33.6	13.4

Source List: *(values in parentheses indicate the source)*

A: Table Transmitted from Steve Schram

B: Halite Presence

C: Well Structure Log, transmitted from Mike Lovejoy

D: Interpolation from Gridding

E: IRI-1 Core Evaluation, transmitted from Roger Day

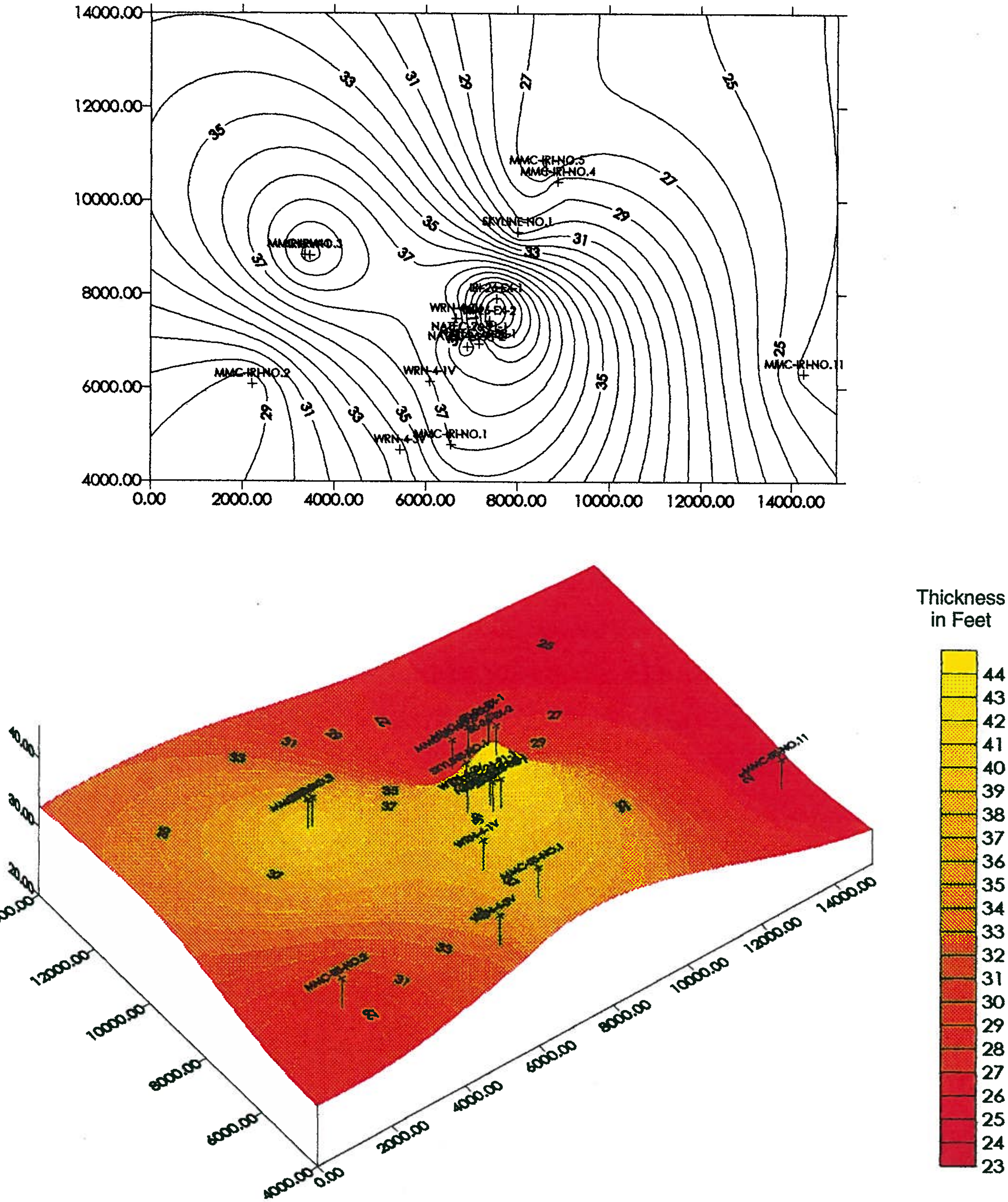


Figure 2-3. Contour and Three-Dimensional Representation of the Equivalent Nahcolite Thickness (in feet)

Table 2-2. Typical Depth and Thicknesses of Overlying Strata from Core Hole 26-88-1

Stratigraphic Marker	Depth (ft)	Thickness (ft)
Uinta Formation	0.0 – 1206.0	1206.0
R-8 Zone	1206.0 – 1392.0	186.0
A-Groove	1392.0 – 1408.0	16.0
Mahogany (R-7) Zone	1408.0 – 1582.0	174.0
Mahogany Marker	1439.0	Not applicable
B-Groove	1582.0 – 1604.0	22.0
R-6 Zone	1604.0 – 1781.0	177.0
L-5 Zone	1781.0 – 1965.0	184.0
Dissolution Surface	1892.8	Not applicable
L-5E	1892.8 – 1903.8	11.0
L-5C	1903.8 – 1913.7	9.9
L-5B	1913.7 – 1925.0	11.3
L-5A—Boies Bed	1925.0 – 1962.5	37.5
OSMB	1949.0 – 1953.4	4.4
Top R-5 Zone	1965.7	Not applicable

The lower aquifer has been further characterized from the simple representation shown in Figure 2-1 based on data developed during the drilling of core hole 26-88-1. The hydrological tests conducted during the drilling of this hole established that the R-6 acts as an aquitard separating contaminated waters in the L-5 above the dissolution surface from potable water in the B-Groove. The "Mahogany Zone" acts as an aquitard between the upper and B-Groove aquifers.

The R-6 aquitard is highly fractured and, like the L-5, contains many collapse structures (breccias) resulting from dissolution of soluble nahcolite and halite. However, water production during drilling showed the R-6 to be tight and an aquitard relative to the L-5 which produced approximately 10 gpm during drilling.

3.0 CAVITY SHAPES AND COLLAPSE MECHANISMS

3.1 Possible Solution Mining Cavern Shapes

Recovery of 40% of the nahcolite resource would remove a layer of material up to 18-ft thick. This quantity of nahcolite could be recovered entirely from the UBB or could be distributed vertically to include some resource from above the UBB.

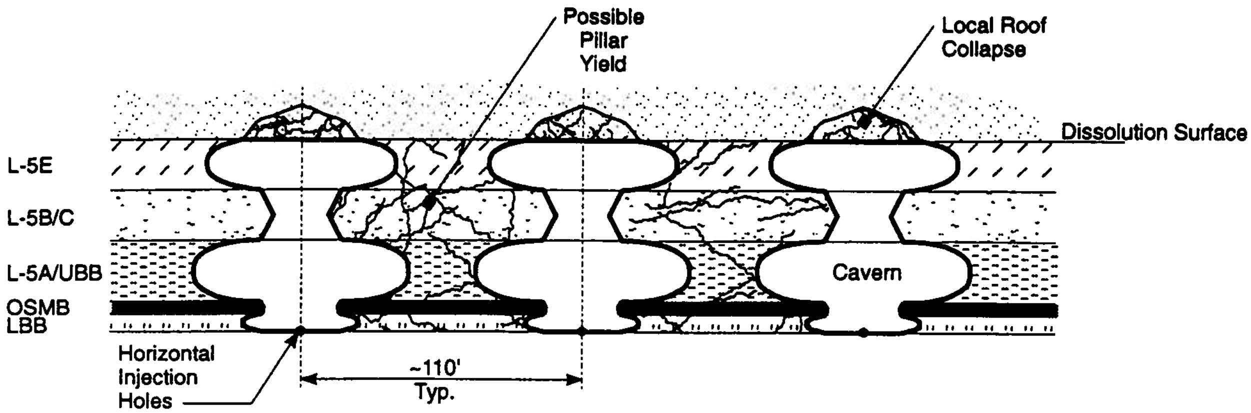
Figure 3-1 shows three possible cavern shape scenarios. The first scenario shows recovery of nahcolite from all beds in the sequence with wider spans developed in the high-bicarbonate strata (UBB and L-5E bed). This results in pillars remaining between the caverns. These pillars could be as much as 60% of the plan area, but locally would be more or less. This is the most credible scenario based on experience with solution mining completed to date. It has been difficult to monitor or survey the development of the cavern shape, but observations from Cavern 1 support the development of an irregular-shaped cavern which is primarily controlled by nahcolite content.

Scenario b shown in Figure 3-1 restricts all nahcolite recovery to the Boies Bed. This is possible and would result in caverns that would often interact and interconnect. However, remnant pillars between the roof and floor would be common. In other locations, wedges of unrecovered nahcolite would remain on the floor between two adjacent caverns. Some load transfer between the roof and floor would be anticipated.

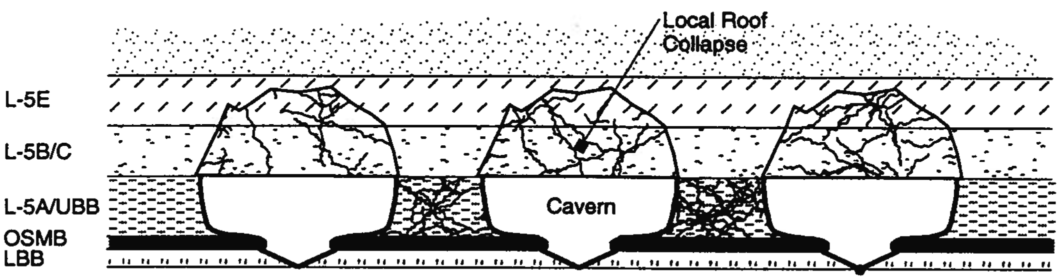
The third scenario somewhat unrealistically assumes that all recovery is focused in a single continuous layer, say in the highest grade section of the UBB. With this scenario, not all of the vertical column of the UBB would be recovered and no pillars or wedges of material would connect between the roof and floor. Clearly during mining of such a large span opening, collapse of the overlying strata would occur.

This last scenario is not considered credible, but is included because it results in the most adverse impacts on the overlying strata. With this scenario, maximum movement of the overlying strata can be anticipated.

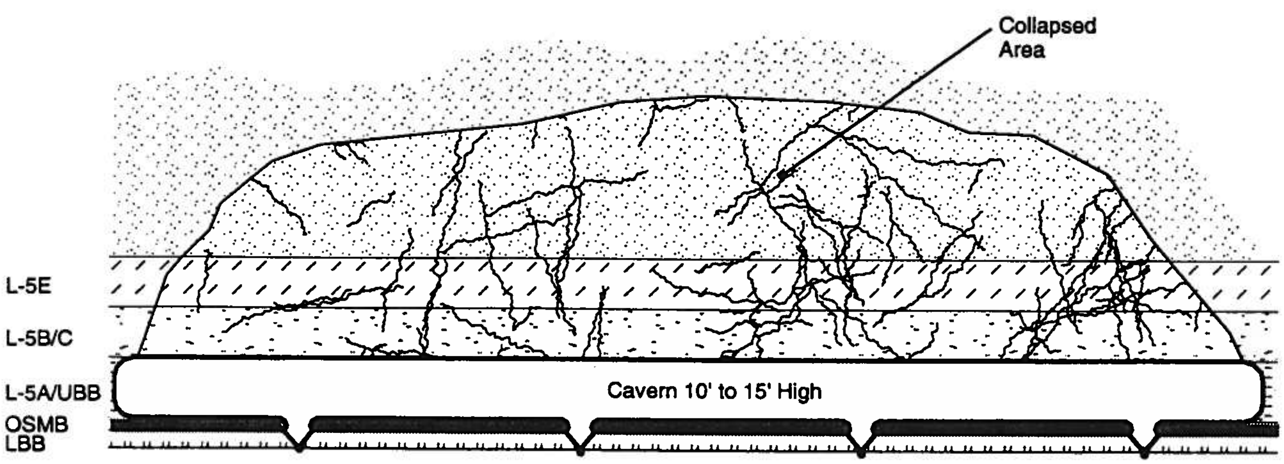
In plan view, the cavern shape is controlled by the location of injection points, duration of injection from each location, and the continuity of the resource. Some areas may be left unmined because of halite intrusion. In plan view, the cavern-to-pillar ratio will be variable and



a) Typical Columnar Mining with Solution Mining in All Resources In and Above Boies Bed



b) Typical Cavern Limited to the Boies Bed



c) Hypothetical Laterally Continuous Cavern at 40% Mineral Recovery

Figure 3-1. Possible Solution Mining Cavern Shapes

incorporate aspects of the three scenarios depicted in Figure 3-1. Also influencing the plan view extraction in the first panel are the caverns or sections of caverns which will not be recovered because of halite intrusion.

3.2 Cave Development

Figure 3-2 shows the caving concept included in the mine plan submitted as part of the Environmental Impact Statement. A similar cave development is anticipated with the new higher extraction mine plan. The bulking of the caved material will inhibit the ultimate development of the caved zone. The height of the caved zone is controlled by the height of the mined seam (the height of the solution cavity) and the bulking factor. For Scenario a of Figure 3-1, the cavern height might be as high as 63 ft and be partially filled with insolubles. From Table 2-1, the equivalent nahcolite thickness (maximum) is 45.1 ft, hence, the nahcolite thickness (maximum) removed from an isolated cavern such as in Scenario a (Figure 3-1) is 45.1 ft (assuming no bulking of the insolubles). In this case, with a bulking factor of 1.3, a cave would develop up about 150 ft above the dissolution surface. For the other scenarios, the height of the cave development would be proportionally less. For example, with a bulking factor of 1.5 for both the insolubles and caving rock, the height of the caving zone would only develop up to 50 ft above the dissolution surface.

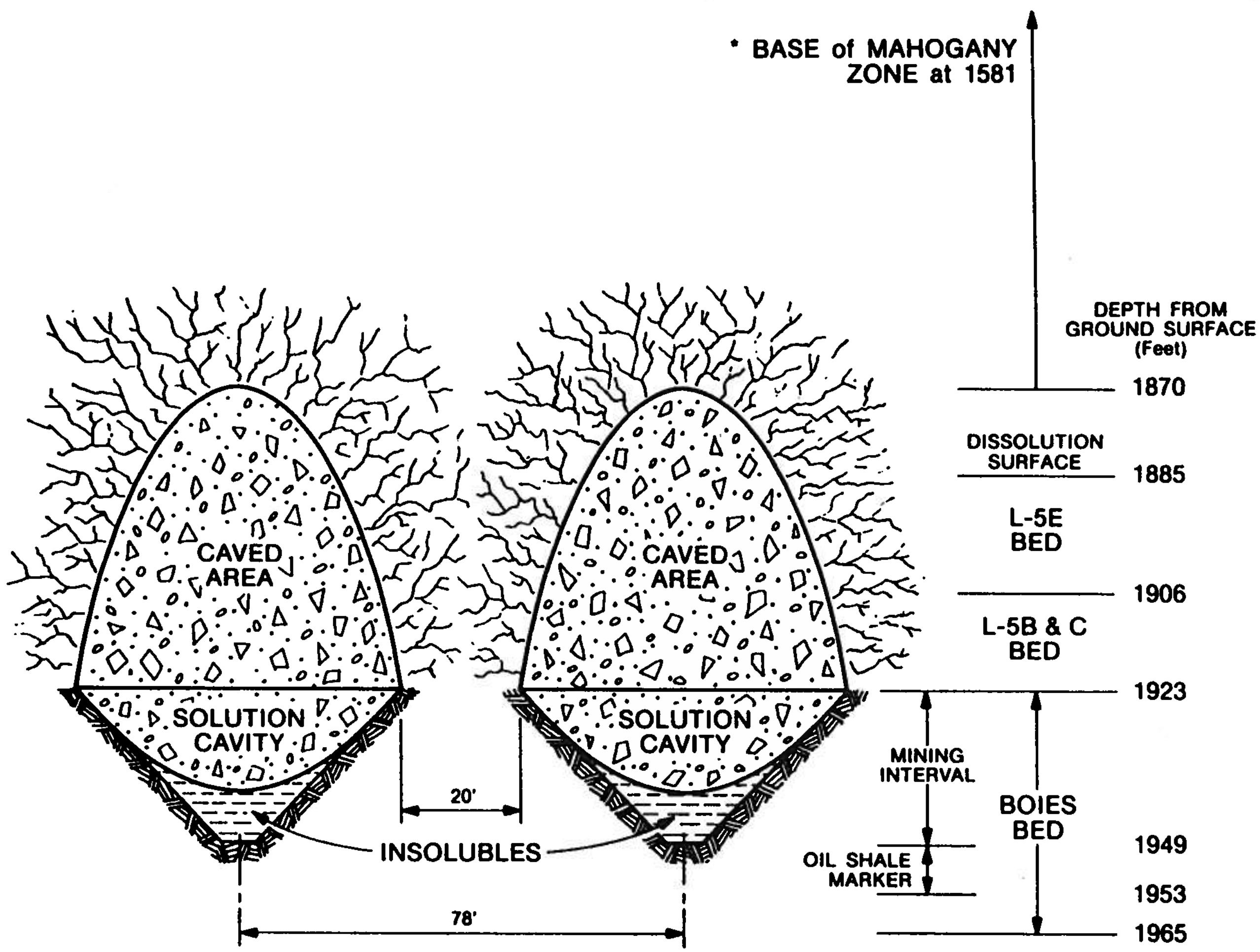


Figure 3-2. End-View Solution Cavity Configuration after Caving (idealized)

4.0 CASE STUDIES AND CRITERIA

4.1 Introduction

The experiences gained from multiple-seam coal and oil shale mining in the Piceance Creek Basin provide the preliminary criteria for the assessment of the solution mining impact on the overlying strata. Section 4.2 presents the case studies for the multiple-seam longwall mining experience and discusses the qualitative indication from these experiences. Qualitative and quantitative criteria derived from these experiences and other sources are summarized in Section 4.3.

4.2 Multiple-Seam Coal Mining

4.2.1 Impact of Minability of the Upper Seam from the Lower Seam Mining

The 1991 Longwall Census (Merritt 1991) shows that of the 78 mines with longwall faces in the United States, 32% of these mines have mining in adjacent strata. About half of these mines report some type of interaction problem with the adjacent coal beds (see Table 4-1). In all but one case, the interburden between the mines is 200 ft or less and the overburden above the upper mine ranges from 800 to 2000 ft. Three mines report severe interaction problems, but in the remaining cases, problems are moderate and manageable.

Table 4-1. Multiple-Seam Longwall Mines

Type of Interaction	Number	Number Reporting Problems
Interaction with longwall workings	16	—
Mines with overlying workings	9	—
Superpositioned gateroads	2	—
Offset gateroads	2	—
Slightly offset	5	4
Mines with underlying workings	7	—
Superpositioned gateroads	2	1
Offset gateroads	2	—
Slightly offset	3	2
Interactions with room-and-pillar workings	9	—
Mines with overlying workings	8	4
Mines with underlying workings	1	1

In the Census, eight mines are classified as subsidence interactions where the longwall operation is mining above an underlying mine. These are cases that could be considered similar to the White River Nahcolite, Inc. case because we are concerned about the effect of mining in the Boies Bed, a lower bed, on the minability of the overlying bed of the "Mahogany Zone." Four of the eight mines reported subsidence-related ground problems, and in all the cases, the interburden is less than 200 ft and the mining height in the lower seam is 5 ft or greater. Fractured strata leading to roof control problems in setup and recovery rooms and in gate entries appear to be a common problem.

Subsidence generally produce two types of ground failure that might affect minability of overlying strata. In the first type, the strata bends in response to subsidence, leading to the formation of a trough. The second type, known as interseam shearing, occurs when subsidence produces highly inclined shear or shear-tensile failures.

The magnitude of roof problems in the subsidence trough is dependent upon the extent of the tension zone. This zone is associated with the formation of fractures and opening of joints which lead to poor roof conditions. The amount of damage subsidence can cause to an overlying strata is largely dependent upon five factors: (1) the lower seam mining height, (2) the interburden thickness, (3) the angle of draw and the caving angle, (4) the time or age of the workings, and (5) the geologic characteristics of the interburden. According to the movement characteristics, the damaged overburden is divided into three zones: caved zone, fractured zone, and continuous deformation zone (Figure 4-1). The caved zone is normally two to eight times the mining height depending on the properties of the immediate roof and the overburden (Peng 1992). As for the fractured zone, the height is approximately nine to eleven times the mining height for a soft and weak rock overburden, and may reach twenty to thirty times the mining height for the hard/strong type overburden (Peng 1992). The fractured zone can be further divided into, from top to bottom, minor, regular, and severe fractured zones. In terms of height, the minor fracture zone occupies one third of the entire fracture zone, while the regular and severe zones occupy the other two thirds.

Interseam shearing can be very damaging to mining in the upper seam because the strata tend to shear and displace as shown in Figure 4-2. Zhou and Haycocks (1986) reported that this interaction is more likely to occur when the operations of both the upper and lower seams are

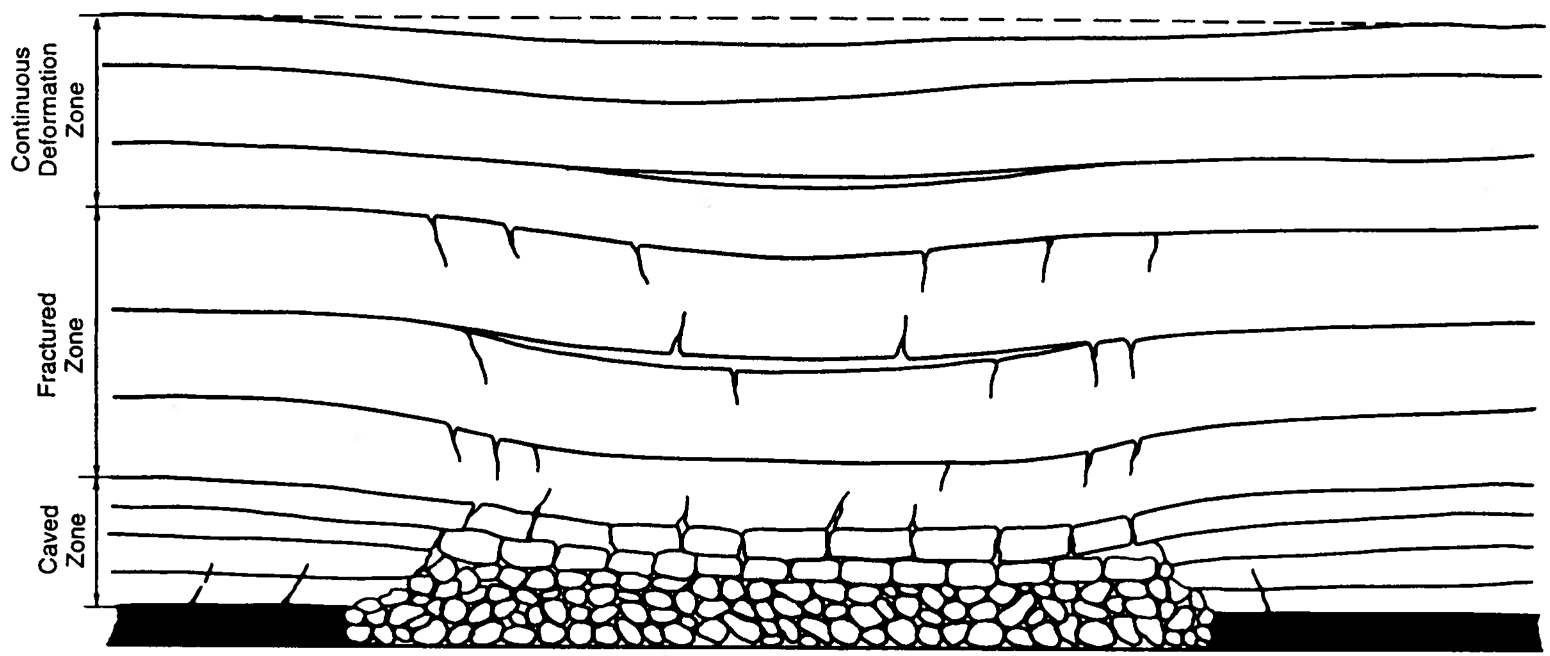


Figure 4-1. Three Zones in Overburden Due to Longwall Mining

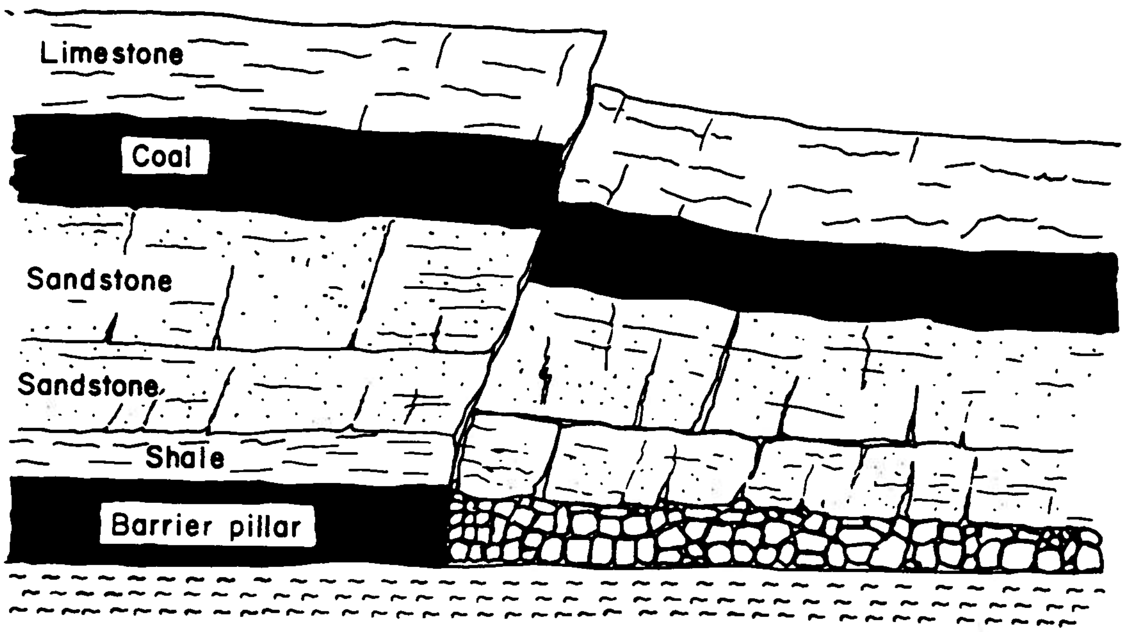


Figure 4-2. Interseam Shearing (adapted from Holland 1947)

active and that the greatest potential for shearing occurs in coal beds lying either within twelve times the extracted seam height or in the caved zone. Fractures and joint systems inherent to the strata are also critical factors in interseam shearing. Faults may complicate or contribute to shear failure.

4.2.2 Effect of Underground Mining on Groundwater

The effects of mining on groundwater have been the subject of many investigations (Booth 1992; Elsworth et al. 1994, etc.). In general, the major factors controlling the groundwater level are summarized as (1) the vertical position of the aquifer relative to the deformed zones in the overburden, (2) the deformed zone in which the aquifer is located, (3) the characteristics of the aquifer, and (4) the permeability of the underlying strata.

The water levels are not usually affected by the mining when the aquifer is located in the continuous deformation and minor fractured zones. If the aquifer is underlain by good permeable strata, the water level will never change. If the aquifer is located above regular coal measure rock, the water level will change somewhat as the face of the longwall approaches. When the strata movement ceases, the water level will recover either partially or completely.

The fractures in the regular and severe fractured zones cut through the entire zone and are well connected both horizontally and vertically. When the aquifer is located in the regular and severe fractured zones with a highly permeable underlying strata, water will most likely drain to the caving zone during mining and will seldom recover after mining.

The fractures are very wide, and water conductivity is excellent in the caved zone. When the aquifer is located in the caved zone, the water generally will not reappear once lost during mining.

4.3 Evaluation Criteria

The evaluation criteria to be applied to the high-extraction solution mining option at the White River Nahcolite, Inc. lease are derived from the multiple-seam mining experiences and other sources. For the discussion in this section, the criteria are divided into qualitative and quantitative categories.

The qualitative criteria based on the caving mechanism described in Figure 4-1 are:

- Solution mining impact to the protection of aquifer and minability of oil shale is minimum if the strata of aquifer and oil shale are located in the continuous deformation zone.
- Solution mining impact to the protection of aquifer and minability of oil shale may range from insignificant to adverse if the strata of aquifer and oil shale are located in the fractured zone. For the minor fractured zone, the impact should be insignificant. For the severe fractured zone, the impact could be adverse.
- Solution mining impact to the protection of aquifer and minability of oil shale would be unacceptable if the aquifer or oil shale were located in the caved zone.

With 40% extraction of the nahcolite reserve, solution mining could yield approximately 16 ft of equivalent mining height (H). The caved zone is predicted to be from 32 to 128 ft (2 to 8 H) with the fractured zone extending up to 144 to 176 ft (9 to 11 H) from the roof of the cavern. The stratigraphy presented in Table 2-2 indicates that the interburden height from the dissolution surface to the B-Groove is approximately 288 ft. Judging from this information, the impact is most probably insignificant.

Quantitative criteria for aquifer protection are summarized in the SME Mining Engineering Handbook (SME 1992). The damage criterion is expressed in terms of horizontal strain and is 0.005. No explicit quantitative criteria was found for the assessment of minability. However, Chekan and Listak (1993) suggest that beds located in the caving zone (three to six times the mining height) may not be minable. The strain criterion of 0.005 is also suggested for both the assessment of impact to the aquifer protection and minability of oil shale.

5.0 ANALYTICAL EVALUATION OF PROPOSED MINE PLAN

5.1 Introduction

Numerical analyses were conducted to evaluate the potential impact of mining on overlying strata. The scenario with cavern width extending to 800 ft was simulated using two-dimensional plane-strain finite difference analysis techniques. An analysis was also completed for two panels separated by a 200-ft barrier pillar. The stresses and deformations predicted for the aquitard, the aquifer, and the "Mahogany Zone" were evaluated against the design criteria summarized in Section 4.3. A surface subsidence prediction based on the integration of an influence function is also presented as an indication of long-term subsidence from potential high-extraction solution-mined panels.

5.2 Two-Dimensional Finite-Difference Analysis

5.2.1 Stratigraphy and Model Parameters

The stratigraphy reported for core hole NaTec 26-88-1 (Agapito Associates, Inc. 1988), presented in Table 2-2, is used for representation of the in situ condition in the analysis. The stratigraphic units and their related geomechanics properties used in the analysis are listed in Table 5-1. The geomechanics properties include Rock Quality Designation (RQD), intact elastic and rock mass elastic moduli, and Poisson's ratio. The rock mass Poisson's ratio is assumed to be equivalent to the intact value. Reduction factors for the rock mass inhomogeneities in elastic modulus were calculated based on the RQD and the formula proposed by Baczynski (1982). The reduction factor ranges between 0.1 to 0.2 for the lower RQD category rock and 0.5 to 0.75 for the good RQD category rock.

Two scenarios for caving were simulated in the finite difference analysis. The first one assumes caving occurs within the saline zone with a bulking factor of 1.3. The second scenario extends the caving zone to R-5 with a smaller bulking factor of 1.1. The thicknesses of the caving zone were predicted to be 50 and 160 ft for the two scenarios, respectively. The calculation of the caving zone thickness is documented in Appendix A. The elastic modulus for the material in the 50-ft caving zone was assumed to be 7000 psi or about 15% of the estimated in-place modulus of the L-5 zone. This estimated elastic modulus was conservatively based on properties

Table 5-1. Geomechanics Properties

Stratigraphic Unit	RQD*	Intact Elastic Modulus** (psi)	Poisson's Ratio **	Reduction Factor	Rock Mass Elastic Modulus (psi)
Uinta Formation	60	1.66E+06	0.17	0.18	305440.0
R-8	60	2.89E+06	0.25	0.18	531760.0
A-Groove	28	2.13E+06	0.21	0.14	296496.0
R-7	47	1.00E+06	0.35	0.17	165800.0
B-Groove	15	2.91E+05	0.31	0.12	35211.0
R-6	31	1.00E+06	0.35	0.14	143400.0
L-5	43	2.91E+05	0.31	0.16	46618.2
DS-RB, RB-BB, OSMB	90	5.63E+05	0.35	0.73	413382.8
RB	90	7.00E+04	0.40	0.73	51397.5
UBB	90	5.91E+05	0.19	0.73	433941.8
R-5	84	1.00E+06	0.35	0.57	574050.0
50' rubblized material***	0	NA	0.19	NA	7000.0
160' rubblized material	5	2.91E+05	0.31	0.11	31137.0

DS—Dissolution surface
RB—Rubber bed
OSMB—Oil shale marker bed
UBB—Upper Boies Bed
* Data from 26-88-1 and regional sources
** Data from 26-88-1
*** Typical sand and gravel material

of sand and gravel because of the expected high porosity of the caved zone. The elastic properties for the material in the 160-ft caving zone are calculated assuming an RQD in the caving area reduced to 5. The material properties for the caving zone are also listed in Table 5-1.

Figures 5-1 and 5-2 show the material models assigned to the various stratigraphic units and the caving zone. The figures are cross sections of the long solution cavities. Only the right-hand half of the 800-ft panel was simulated, with a symmetry condition imposed on the left-hand boundary. For the two-panel analysis, the line of symmetry bisected the 200-ft barrier pillar, and only the 160-ft-high rubblized case was analyzed.

The in situ vertical stress was assumed to be in equilibrium with the weight of the overlying strata, and the two components of the horizontal stress equal to 70% of the vertical stress. This stress field is the same as that used in our earlier analysis (Agapito Associates, Inc. 1990) and is consistent with the few stress measurements made in the Piceance Creek Basin (Wolff et al. 1974 and Mitchell 1981).

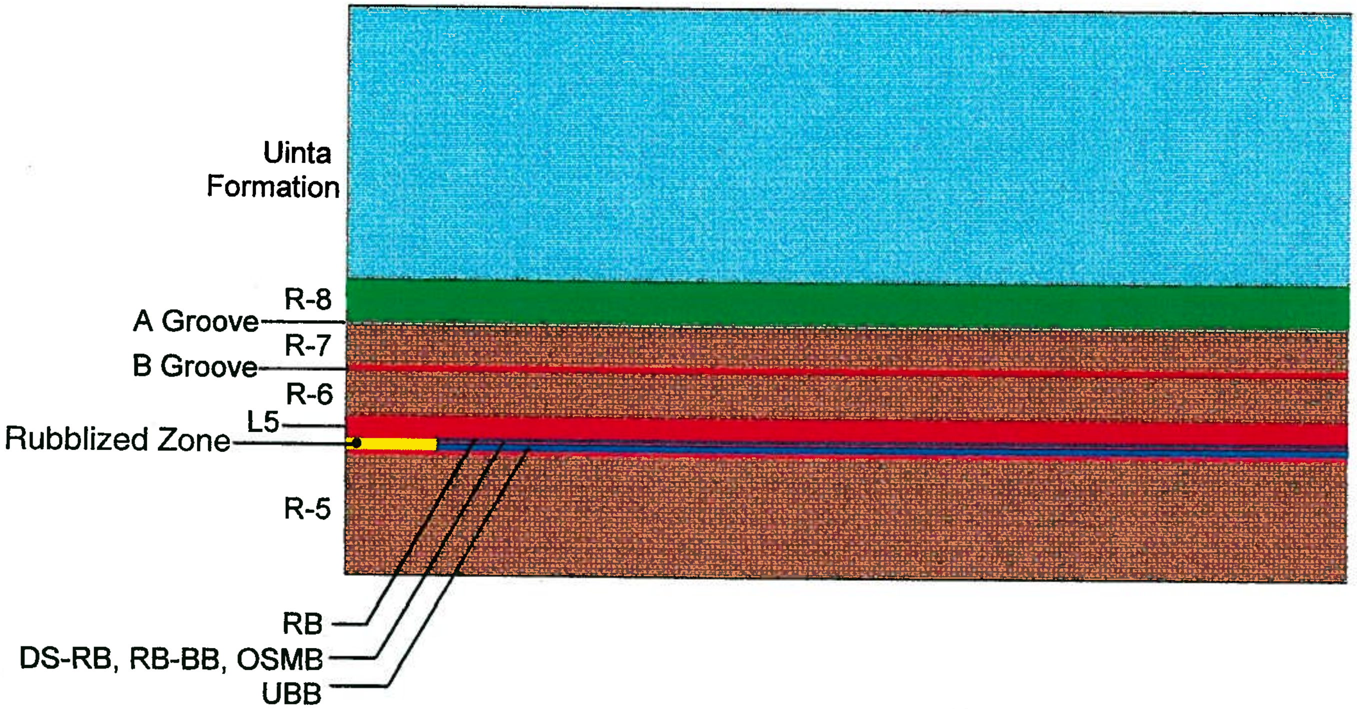


Figure 5-1. Material Models for Finite-Difference Analysis, 50-ft Caving Scenario

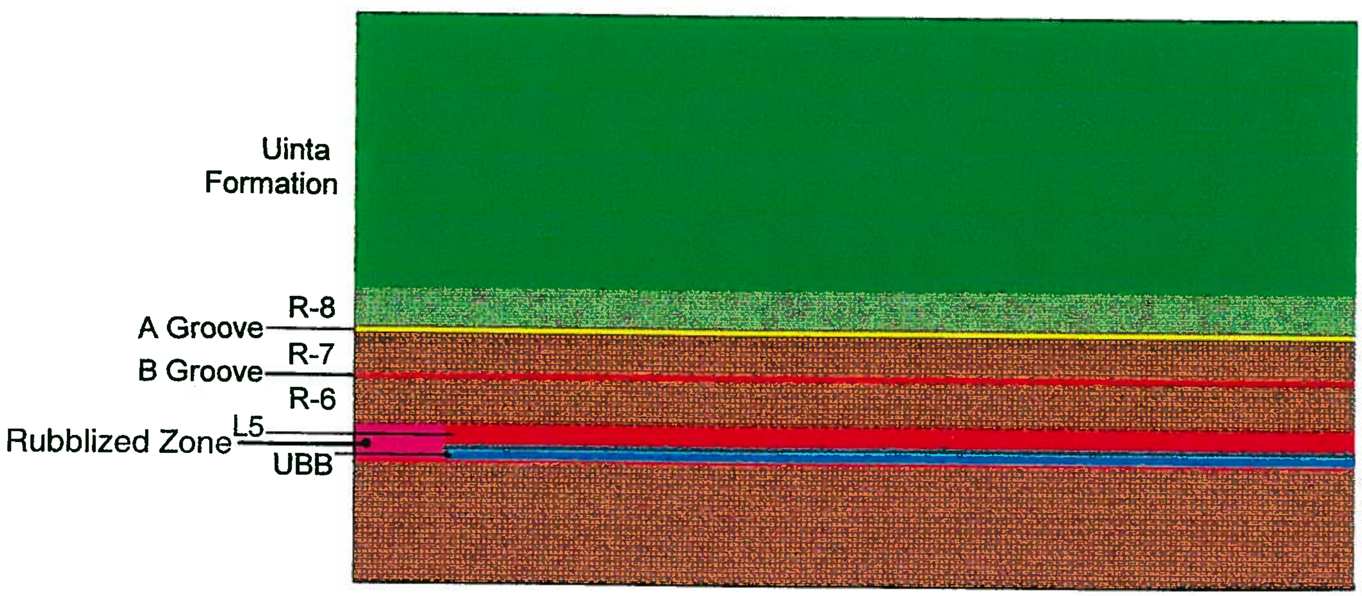


Figure 5-2. Material Models for Finite-Difference Analysis, 160-ft Caving Scenario

5.2.2 Analysis Results

The horizontal and vertical stress contours and yield zones after solution mining and subsequent caving are presented in Appendix B. The results show that stresses in the caving zone are greatly relieved. The plastic yield zones occur mainly within the caving area and around the wall of the solution cavity.

The horizontal strains at locations of interest are presented in Figure 5-3 and 5-4. The shape of the strain profiles agree with the typical horizontal strain curves, with the maximum strains occurring at the point of break and zero strain at the edge of the opening. The results indicate that the mining induced strain for the aquitard (R-6), aquifer, and "Mahogany Zone" are all less than 0.005 and, hence, meet the evaluation criteria. Horizontal strains predicted from the two 800-ft panels analysis are also lower than 0.005.

The surface subsidence predicted from the analyses are shown in Figures 5-5, 5-6 and 5-7. The maximum subsidence and horizontal displacement are predicted to be less than 2 ft above the single panel and approximately 3 ft over the two panels. The subsidence prediction from a continuum model may not be conservative. An empirical approach for prediction of surface subsidence based on the influence function is presented in Section 5.3.

Quantification of the impact of mining on the hydraulic conductivities of the aquifer and aquitard was conducted based on the influence of the stress change on hydraulic conductivities of the aquitard (R-6) and the B-Groove aquifer. The method uses the hyperbolic normal stress closure relationship (Goodman 1976) and the cubic flow rule in the fractured rock mass (Snow 1965). The description of the method and application to the White River Nahcolite, Inc. high-extraction solution mining case is presented in Appendix C. The changes in hydraulic conductivity in the overlying R-6 and B-Groove beds are insignificant compared with the natural variation of the hydraulic conductivities.

5.3 Surface Subsidence Prediction

In addition to the surface subsidence estimates discussed above, a numerical subsidence prediction program was used to predict the long-term maximum possible subsidence based on the extraction of 16-ft equivalent thickness nahcolite. Figure 5-8 shows the location and orientation of the two panels assumed mined to 40% final extraction.

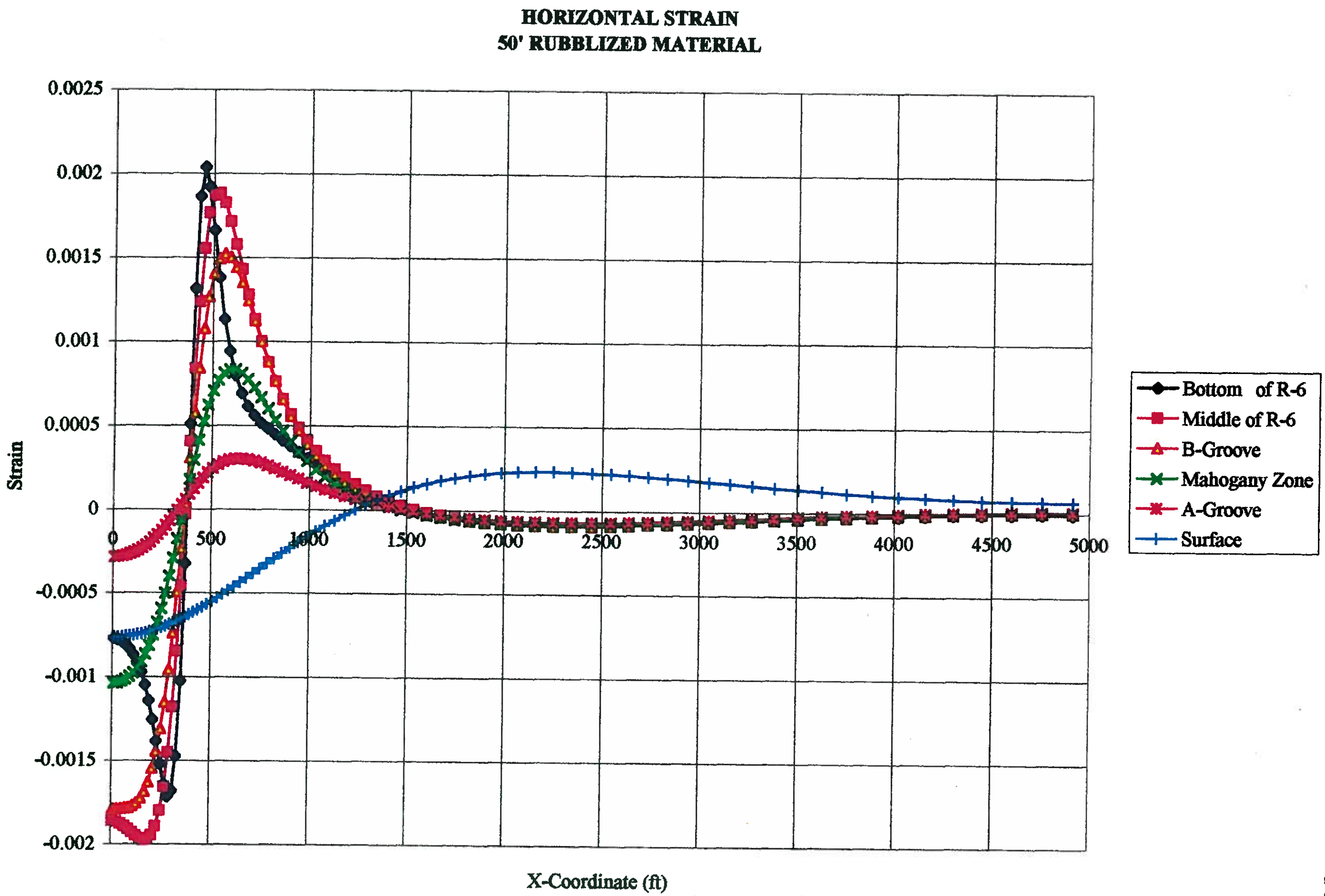


Figure 5-3. Predicted Horizontal Strains for 50-ft Caving Scenario

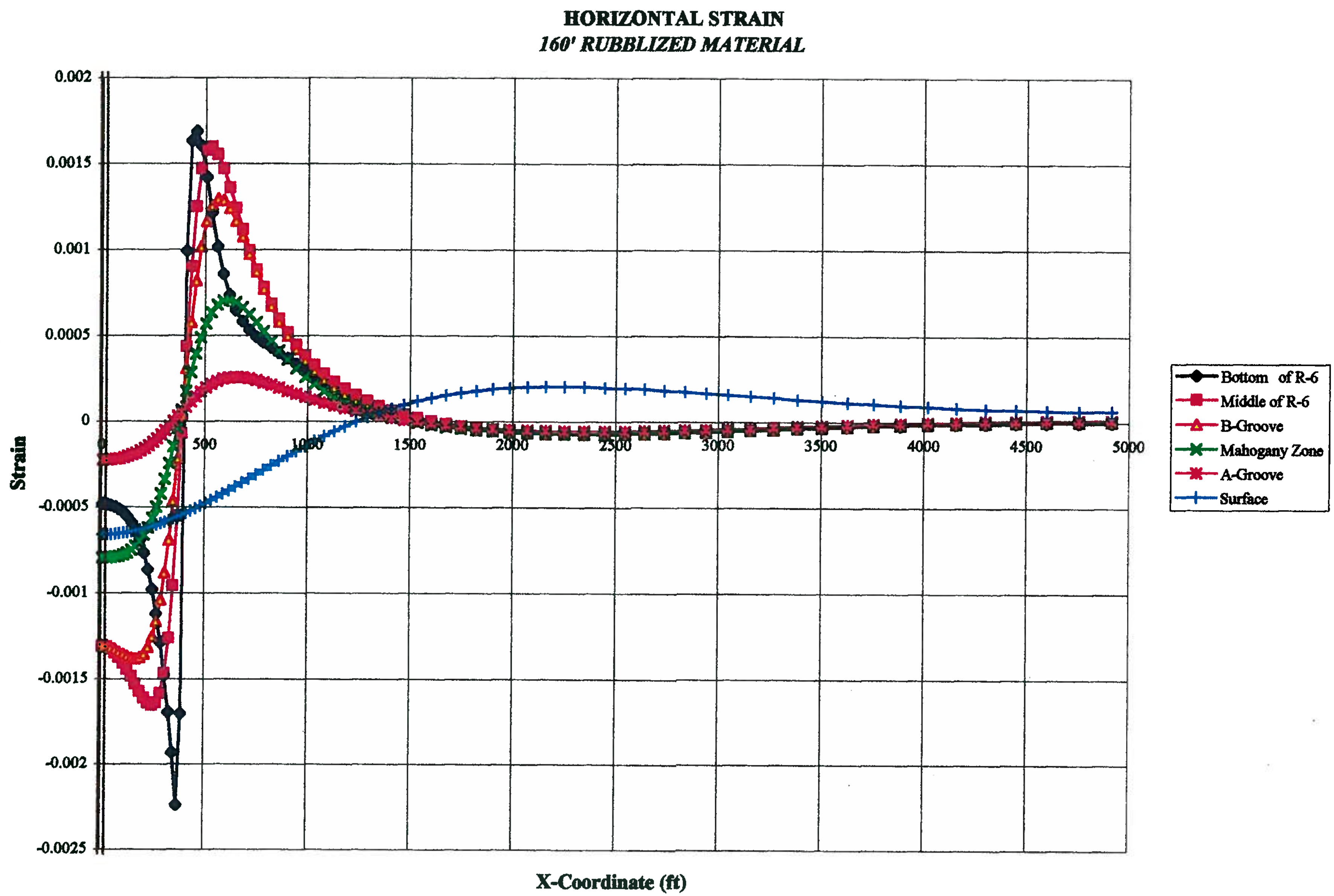


Figure 5-4. Predicted Horizontal Strains for 160-ft Caving Scenario

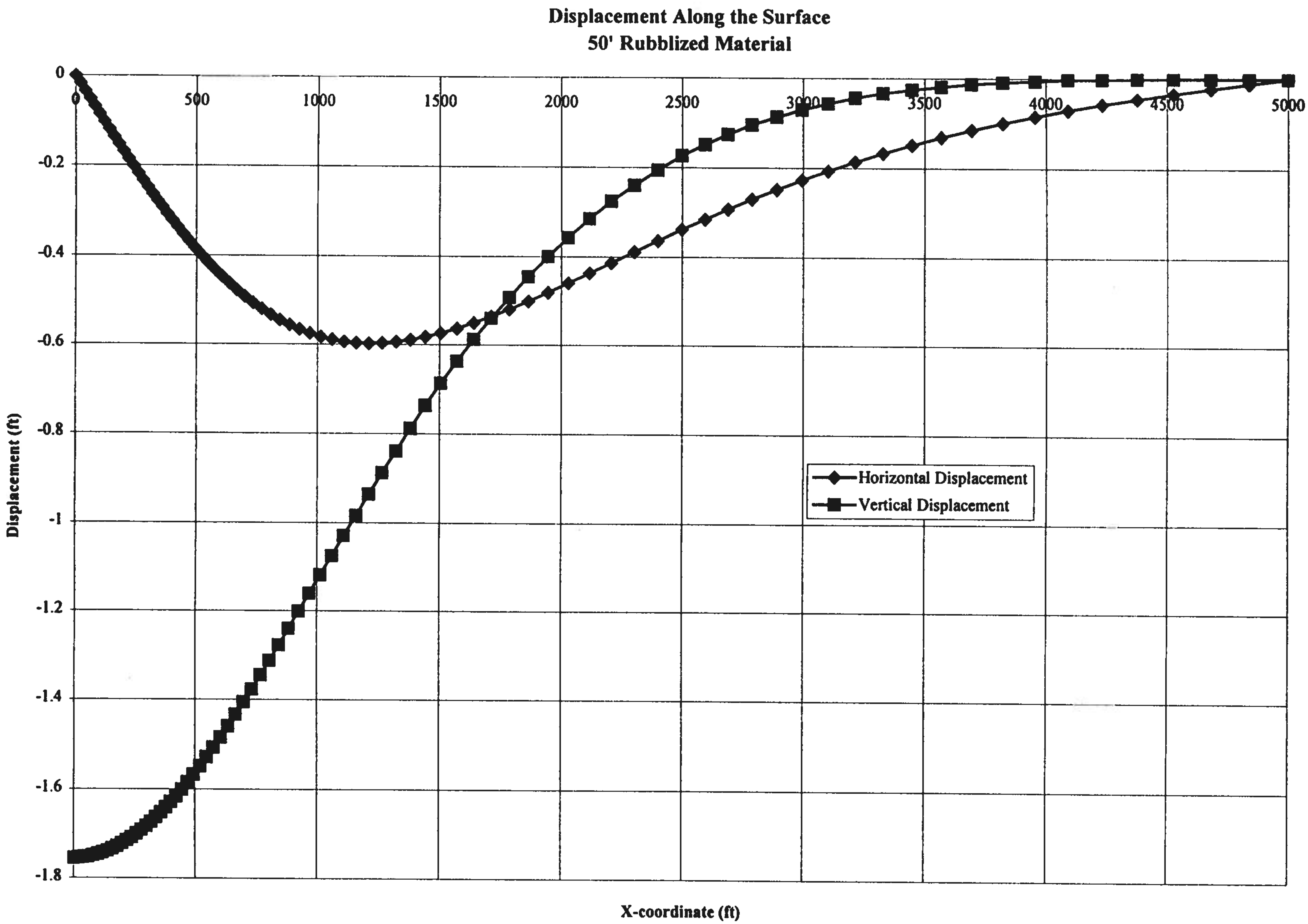


Figure 5-5. Predicted Surface Subsidence and Horizontal Displacement for 50-ft Caving Scenario

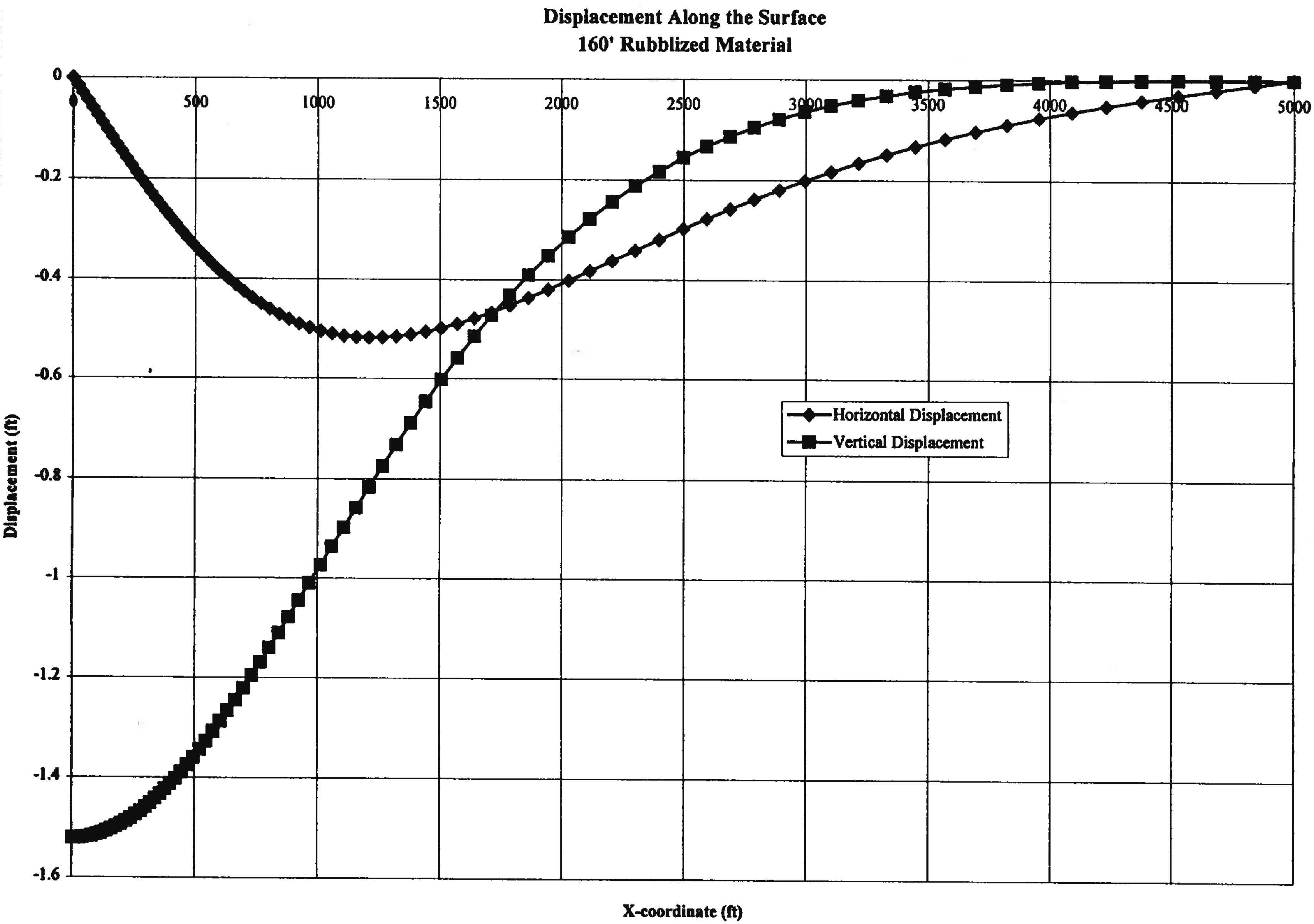


Figure 5-6. Predicted Surface Subsidence and Horizontal Displacement for 160-ft Caving Scenario

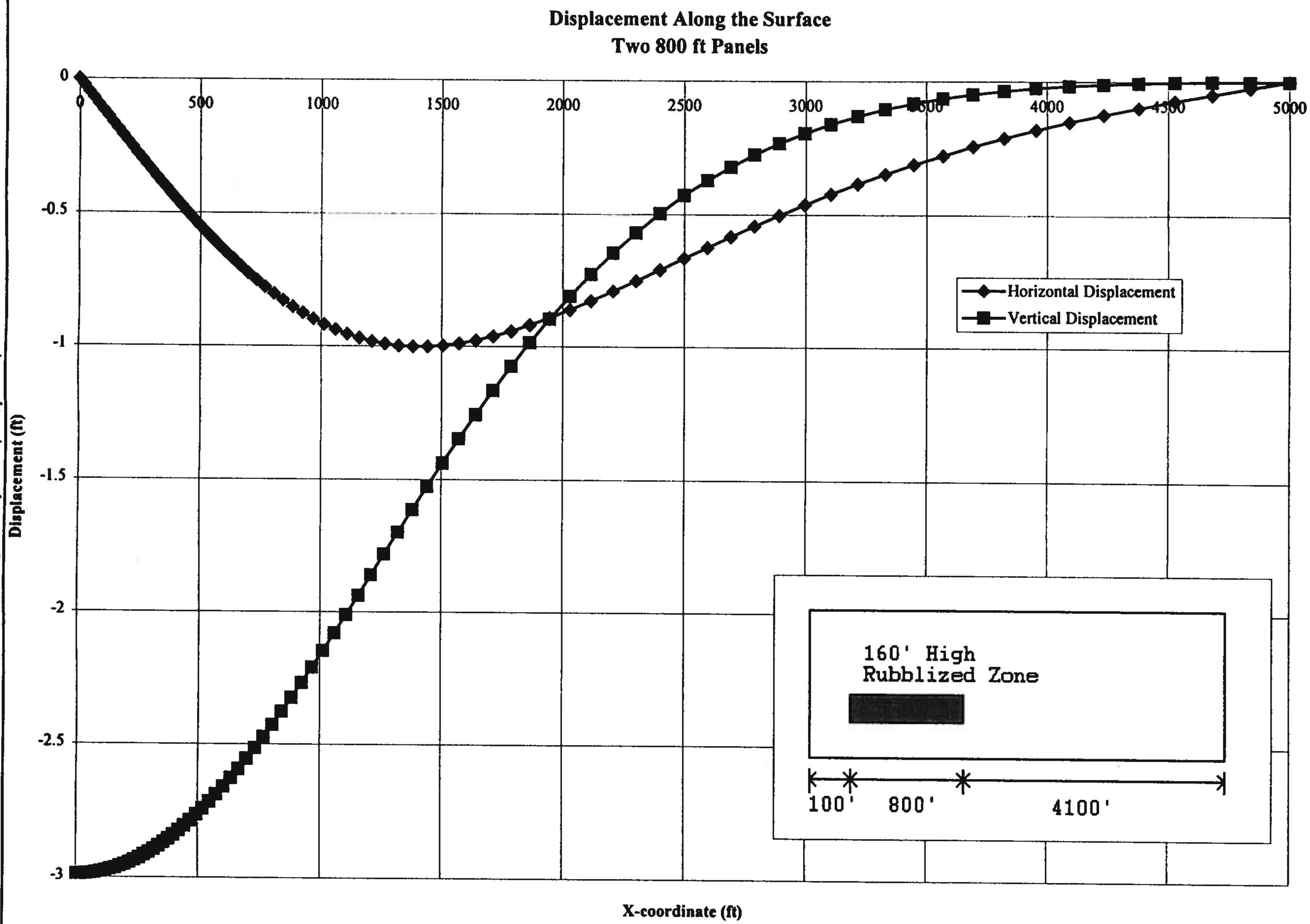


Figure 5-7. Predicted Surface Subsidence and Horizontal Displacement for Two 800-ft Panels

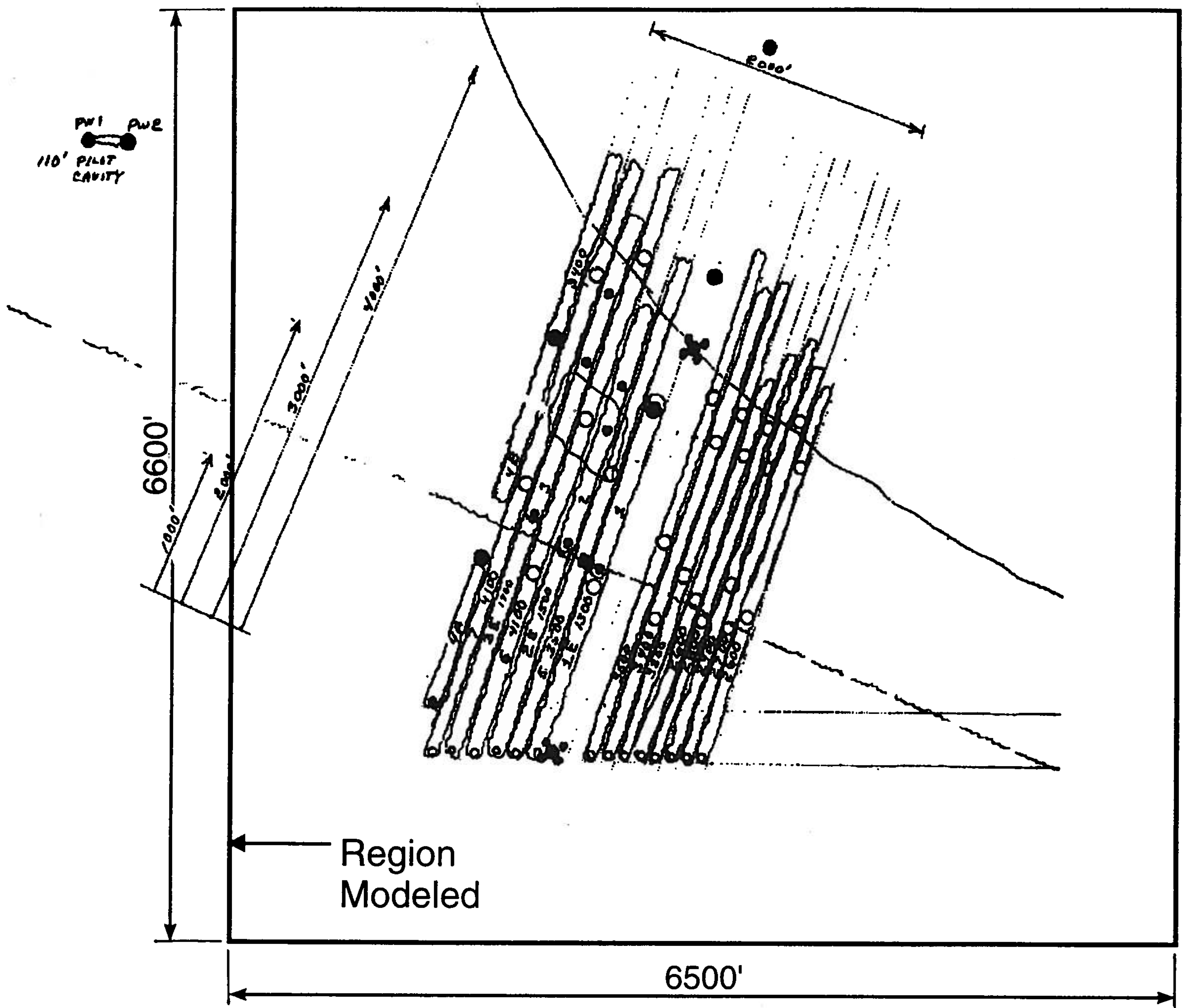


Figure 5-8. Location and Orientation of Solution-Mined Panels

The subsidence prediction program integrates over the area of mining to determine the maximum possible surface subsidence using an influence function. A material property required for the analysis is the angle of draw. For the influence function, we have used a normal distribution function which has been used for many years to predict mine subsidence in the United States and elsewhere — see, for example, SME Handbook Chapter 10.6.

An angle of draw of 45° was assumed based on the soft overburden in the immediate vicinity of mining. Above the A-Groove, the material might be considered hard/strong, resulting in a lower overall angle of draw. The maximum possible subsidence was conservatively assigned as 100% of the extraction height. Experience from coal mining indicates that a reduction factor of 60% to 80% generally yields satisfactory prediction.

Figure 5-9 shows the predicted surface subsidence induced from the mined area for Phases I and II of the mine plane. The maximum possible subsidence is approximately 10 ft. This analysis using the influence function method, indicates a higher possible subsidence than the earlier analysis (shown in Figure 5-7). Bulking of the insolubles in the zone of dissolution (LBB to the dissolution surface) and bulking of the caved material above the solution cavern will reduce the total subsidence from that predicted and shown in Figure 5-9; hence, the subsidence is estimated to be between 3 and 10 ft.

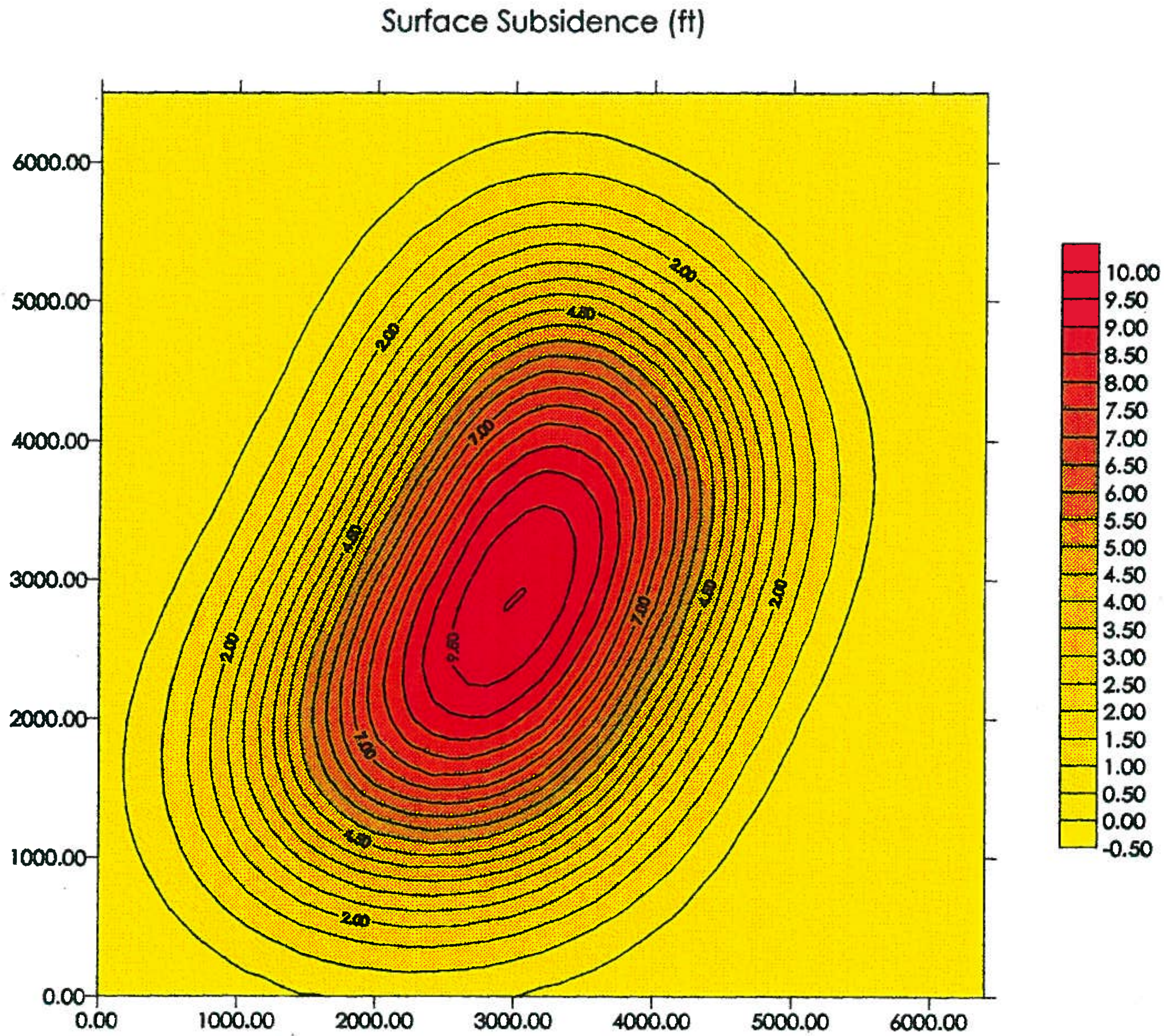


Figure 5-9. Predicted Surface Subsidence Based on Integration of Influence Function

6.0 CONCLUSIONS AND RECOMMENDATIONS

The new mine plan utilizing submersible pumps and balancing of the in-cavern fluid pressures with the surrounding groundwater pressures relieves the requirement of maintaining structural integrity of the roof materials above the Boies Bed. If collapse of the overlying strata were to occur, flow would also be in balance. Solution mining of the nahcolite above the Boies Bed would be possible if the permit constraints of the Environmental Impact Statement were not violated. This report addresses the potential impact of high-extraction solution mining of the Boies Bed and overlying strata on the two controlling permit requirements: (1) to maintain the minability of the high-grade oil shale in the "Mahogany Zone" and (2) to protect the B-Groove aquifer from adverse impacts associated with solution mining operations.

To assess the potential impacts of high extraction on the minability of the oil shale and aquifer protection, the available resource was reviewed, the shape and extent of potential cavities evaluated, and the cavity shape that would have the most impact on aquifer protection and minability of the "Mahogany Zone" evaluated. To assess the impact of solution mining on aquifer protection, the deformation, strains and changes in hydraulic conductivity in the aquitard below the B-Groove aquifer were evaluated. To assess the impact of solution mining on the minability of the oil shale in the "Mahogany Zone," examples of multi-seam mining involving caving with lower seam mining were evaluated and criteria established in the literature applied to the White River Nahcolite, Inc. case. High-extraction mining within panels separated by barrier pillars is recommended to control the potential caving above the mine panels and to minimize surface subsidence. Forty-percent extraction of the available nahcolite resource in and above the Boies Bed and below the dissolution surface within such panels is possible without adverse impact on the minability of the "Mahogany" oil shale or the B-Groove aquifer. Recovery of more than 40% nahcolite is possible without damage to the aquifer or oil shale minability, but the upper limit of the allowable or acceptable nahcolite extraction was not established in this study.

Collapse of the overlying strata, bulking of the caved material, and deformation of the overlying strata including the R-6 aquitard, the B-Groove aquifer and the "Mahogany Zone" were shown to be acceptable while preserving the integrity of the aquitard and the aquifer, and the minability of the "Mahogany Zone."

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APPENDIX A

CALCULATION OF THE HEIGHT OF CAVING ZONE

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CALCULATION OF THE HEIGHT OF THE CAVING ZONE

Idealized Stratigraphic Cross Section of Boies Bed

Depth		**Nahcolite Content**
10'	L-5E	80%
20'	L-5B and L-5C	50%
22'	L-5A (Upper Boies Bed)	80%
5'	Oil Shale Marker Bed	50%
3'	Lower Boies Bed	80%

The equivalent thickness of nahcolite:

$$H = 10' \times 80\% + 20' \times 50\% + 22' \times 80\% + 5' \times 50\% + 3' \times 80\% = 40.5' .$$

With 40% extraction of the nahcolite reserve, the extraction equivalent thickness is:

$$40.5' \times 40\% = 16.2' .$$

Scenario A. In the Environmental Impact Statement, a bulking factor of 1.3 was used. The following formula was used for predicting caving zone:

$$H = \frac{h}{k-1} , \qquad \text{(A-1)}$$

where H is the height of the cavity zone,

h is the mining height, and

k is the bulking factor;

therefore,

$$H = \frac{16.2'}{13-1} = 48.6' . \qquad \text{(A-2)}$$

Scenario B. Also assuming a bulking factor of 1.1, the caving zone height is then

$$H = \frac{16.2'}{1.1-1} = 162' . \qquad \text{(A-3)}$$

APPENDIX B

TWO-DIMENSIONAL FINITE DIFFERENCE ANALYSIS RESULTS

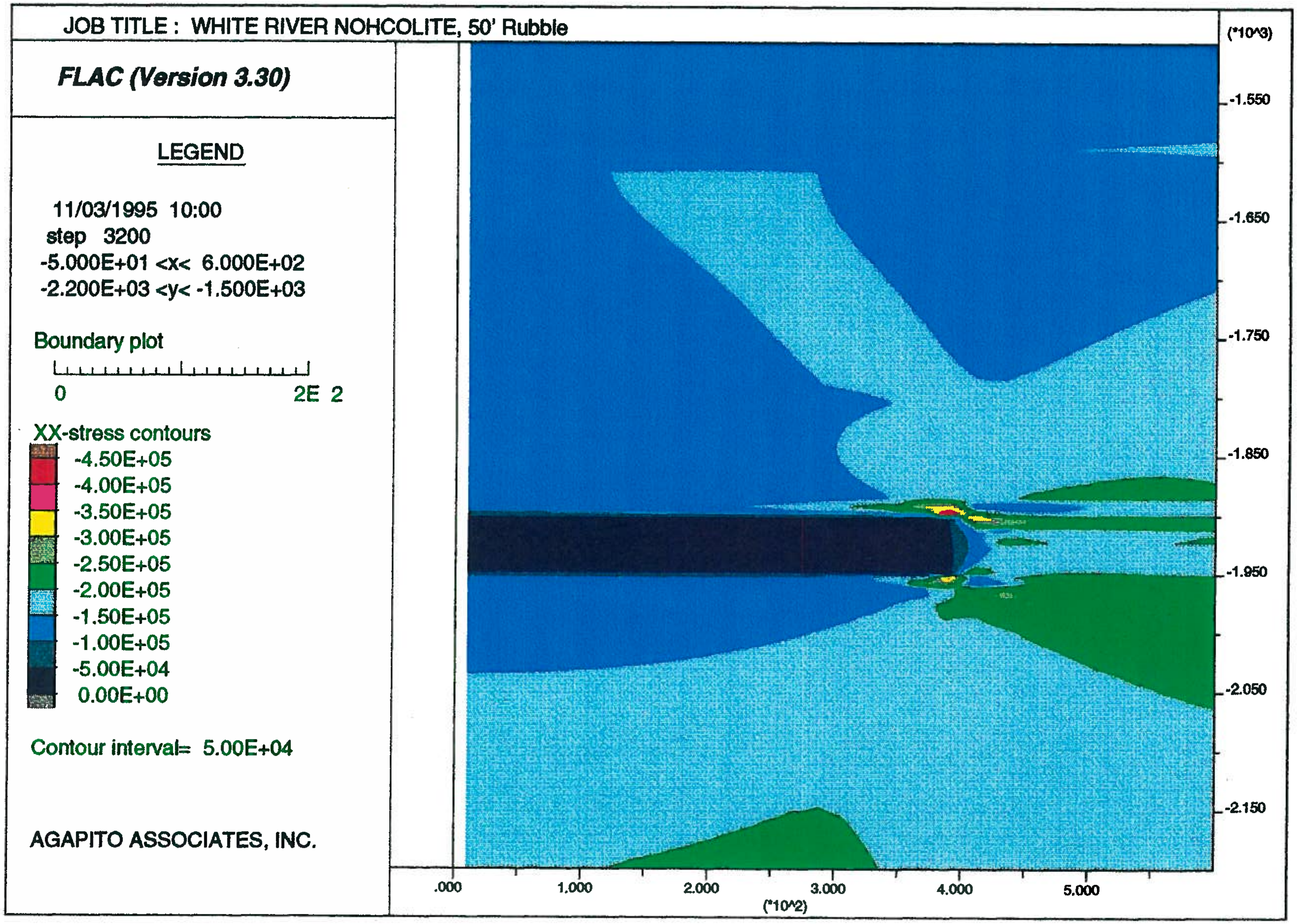

Figure B-1. Horizontal Stress Results for 50-ft Caving Scenario

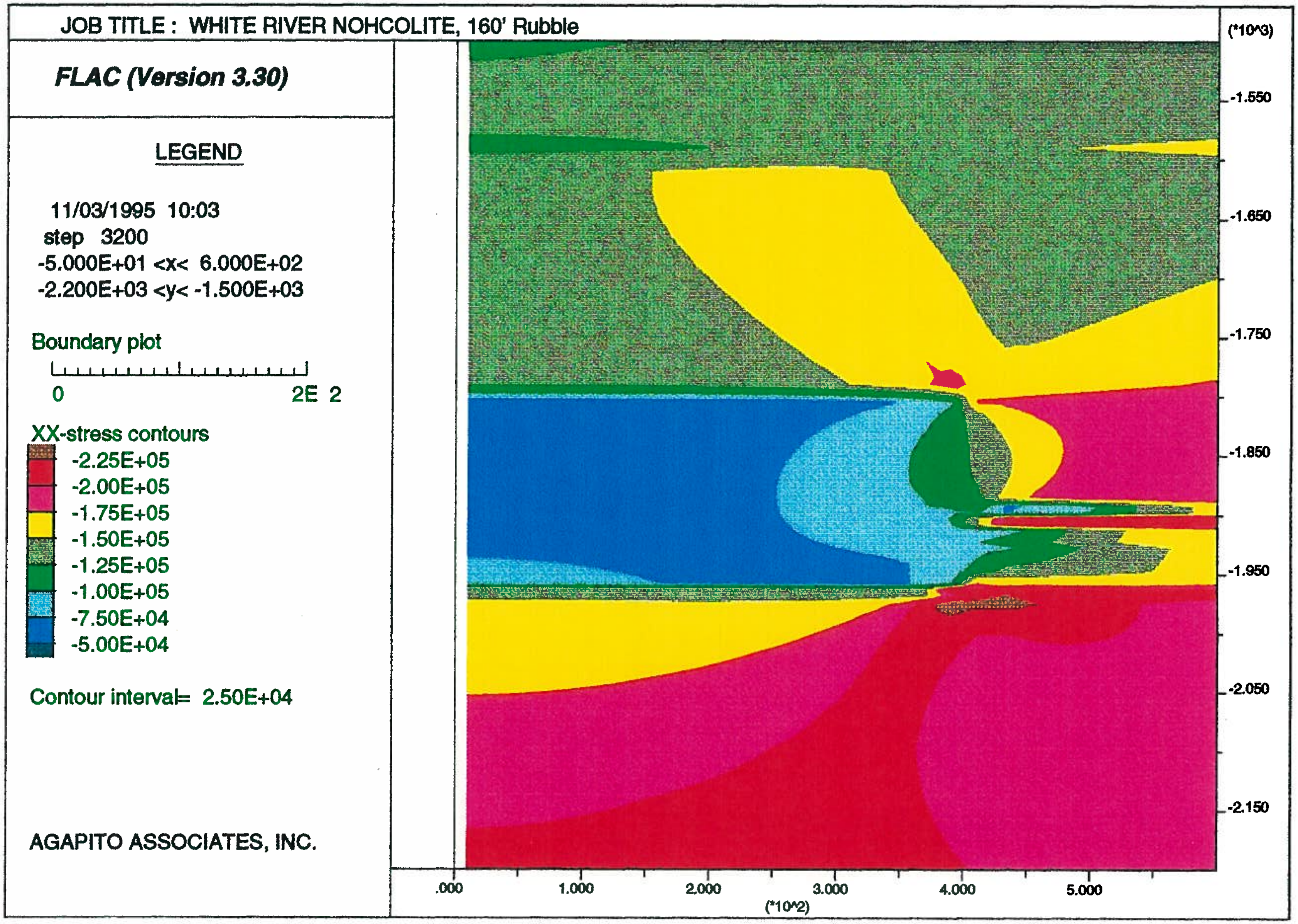

Figure B-2. Horizontal Stress Results for 160-ft Caving Scenario

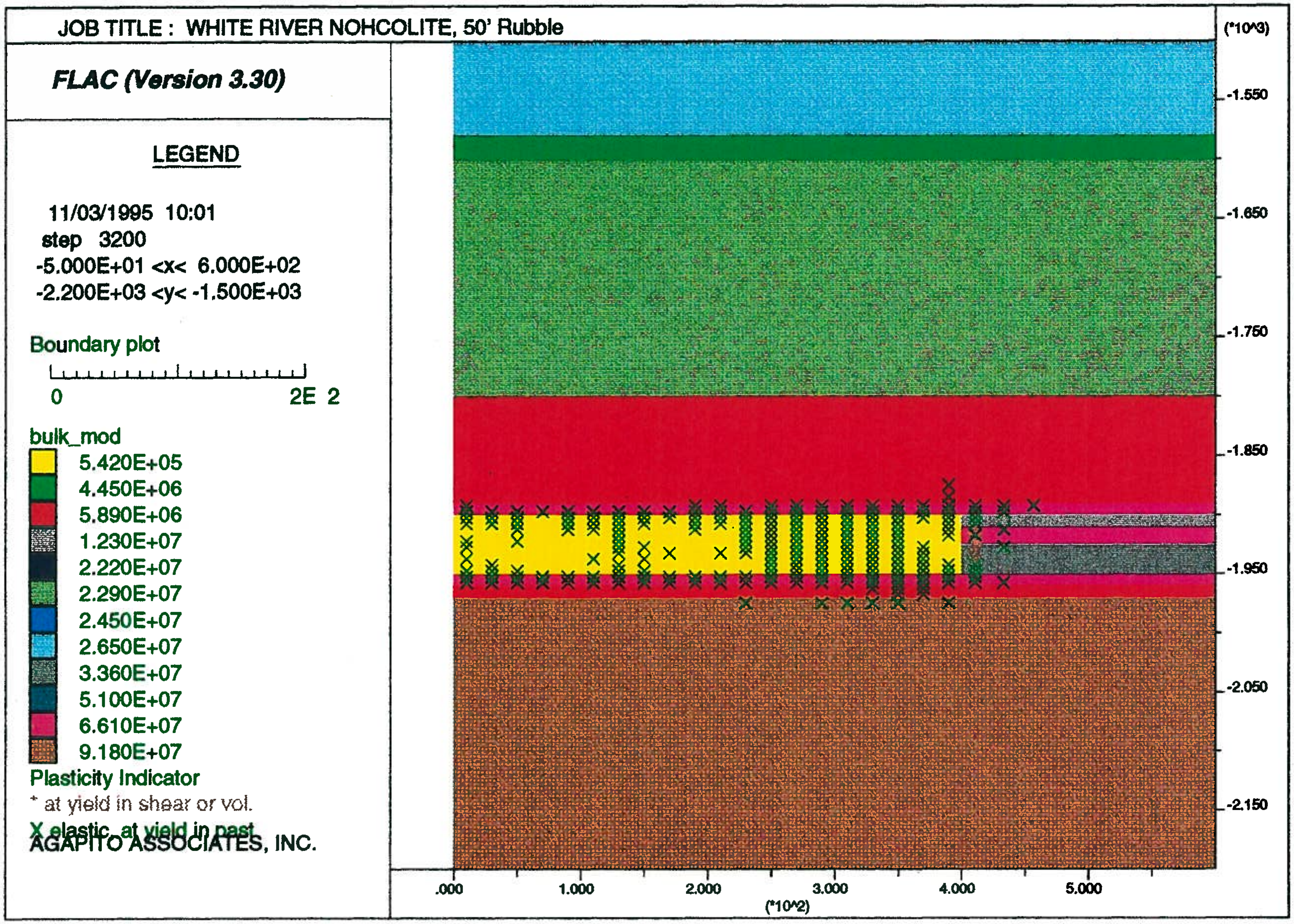

Figure B-3. Plastic Yield Zones for 50-ft Caving Scenario

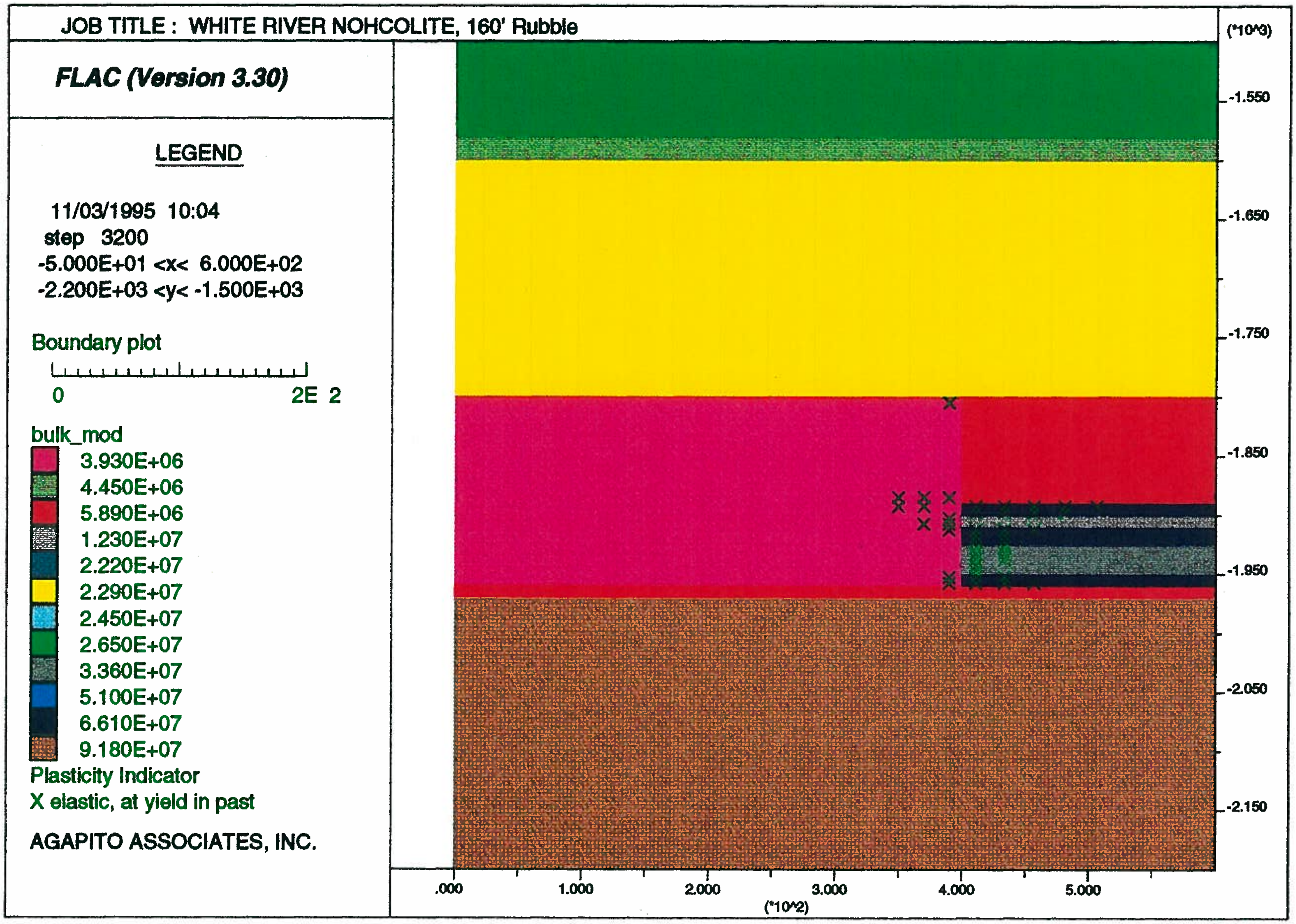

Figure B-4. Plastic Yield Zones for 160-ft Caving Scenario

APPENDIX C

EVALUATION OF CHANGES ON THE HYDRAULIC CONDUCTIVITIES IN THE AQUITARD AND AQUIFER

APPENDIX C

EVALUATION OF CHANGES ON THE HYDRAULIC CONDUCTIVITIES IN THE AQUITARD AND AQUIFER

Evaluation of the impact of mining on the hydraulic conductivities of the aquifer and aquitard was conducted based on influence of the stress changes on hydraulic conductivities of the aquitard (R-6) and B-Groove aquifer. The calculation utilized the hyperbolic normal stress closure relationship (Goodman 1976) and the cubic flow rule in the fractured rock (Snow 1965).

The hyperbolic normal stress closure relationship describes the closure of fracture varying hyperbolically with normal stress. The cubic flow rule is used to describe fluid flow in a fracture, i.e. the volumetric flow rate is proportional to the cube of the effective joint aperture. Figure C-1 graphically presents the major non-linearities of fluid flow in a fracture. The horizontal post-mining states are presented in Figures C-2 and C-3. Based on a generic hyperbolic normal stress closure curve as presented in Figure C-4, the ratio of the pre- and post-mining closures for the vertical joints can be obtained with the stress information. The ratio of the hydraulic conductivity is then directly obtained as the cube of the ratio for the closure. Figures C-5 and C-6 present the estimation of the changes on hydraulic conductivities in the aquitard and aquifer.

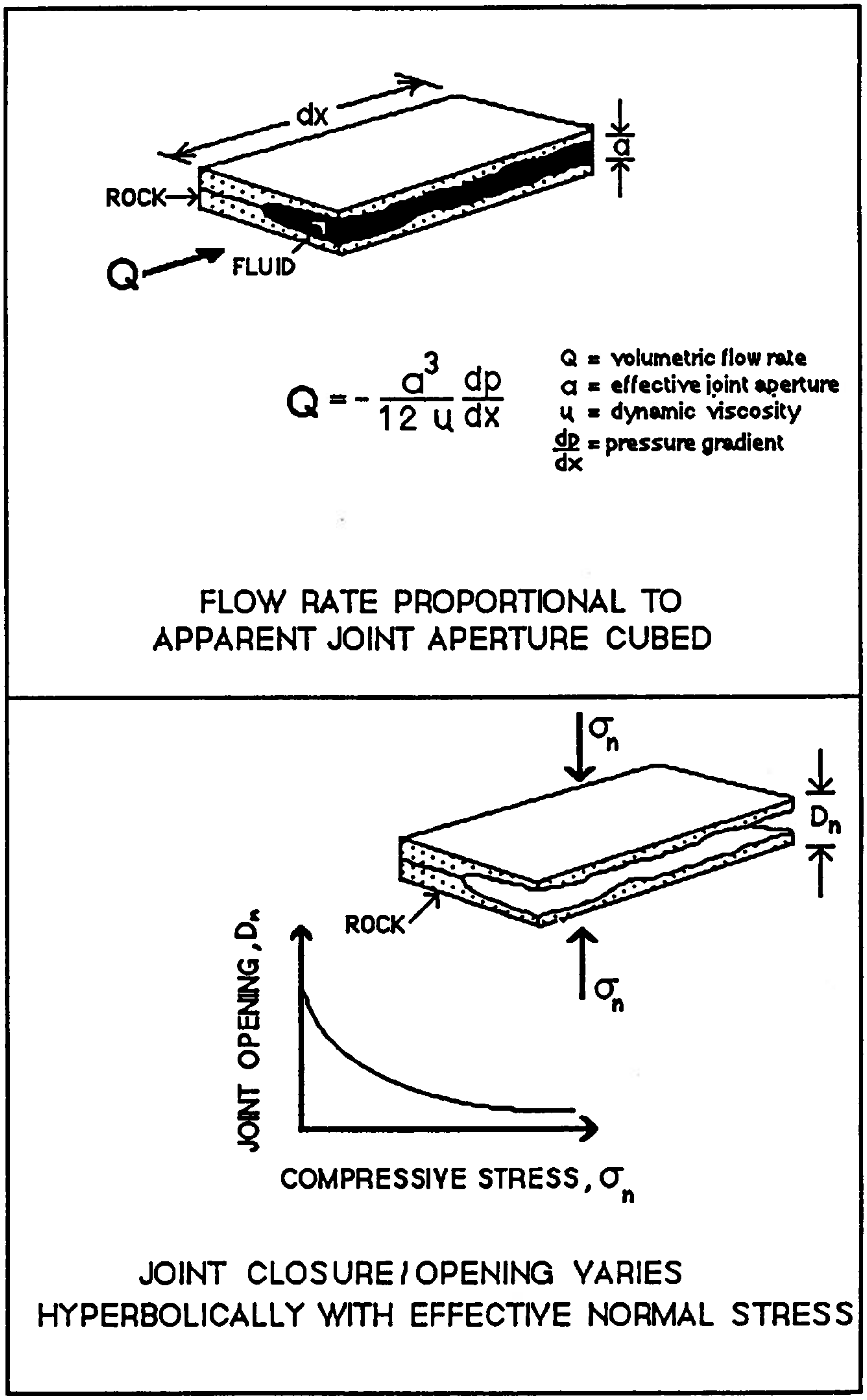

Figure C-1. Fluid Flow in a Natural Fracture

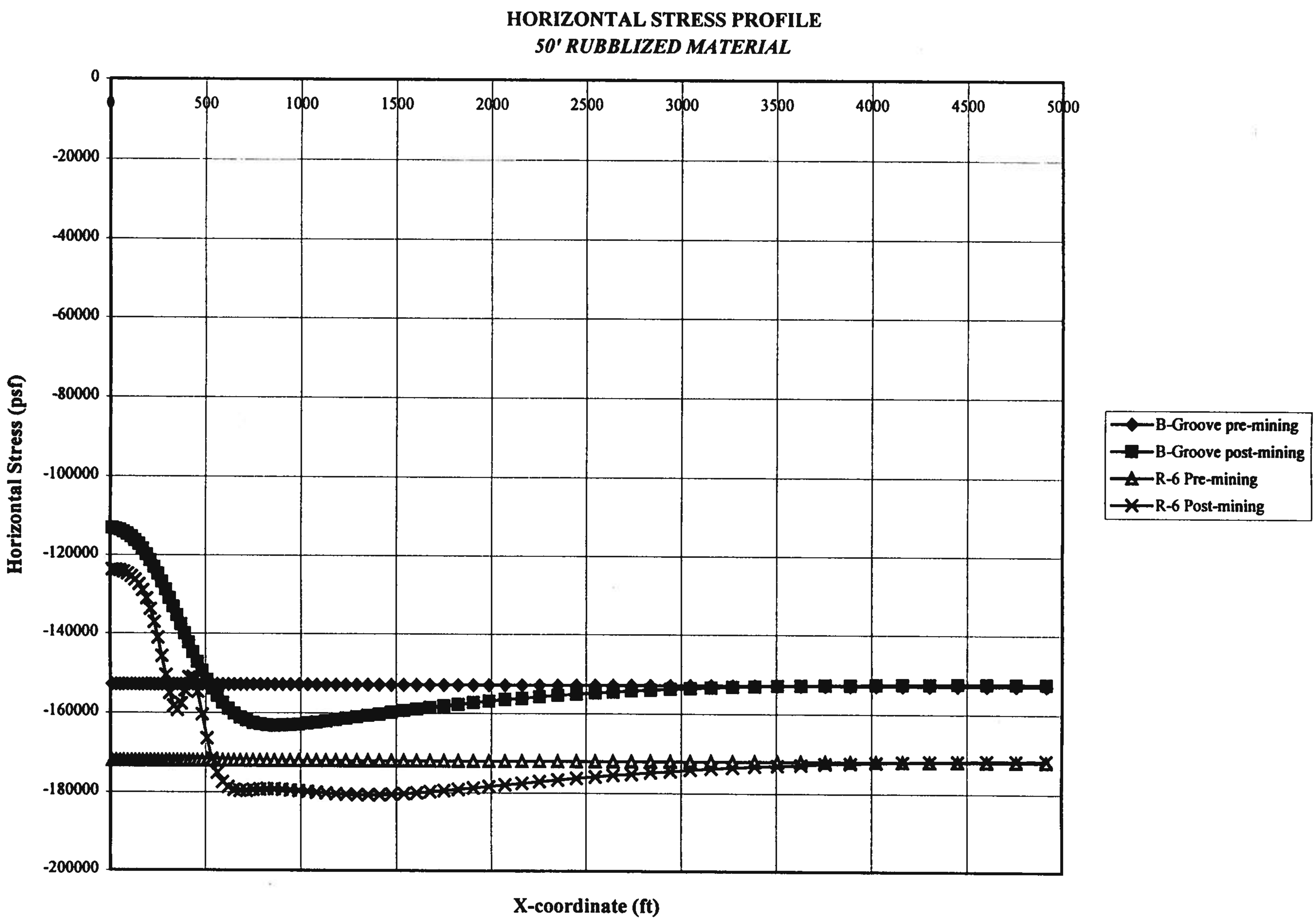

Figure C-2. Horizontal Stress Profiles for the 50-ft Caving Scenario

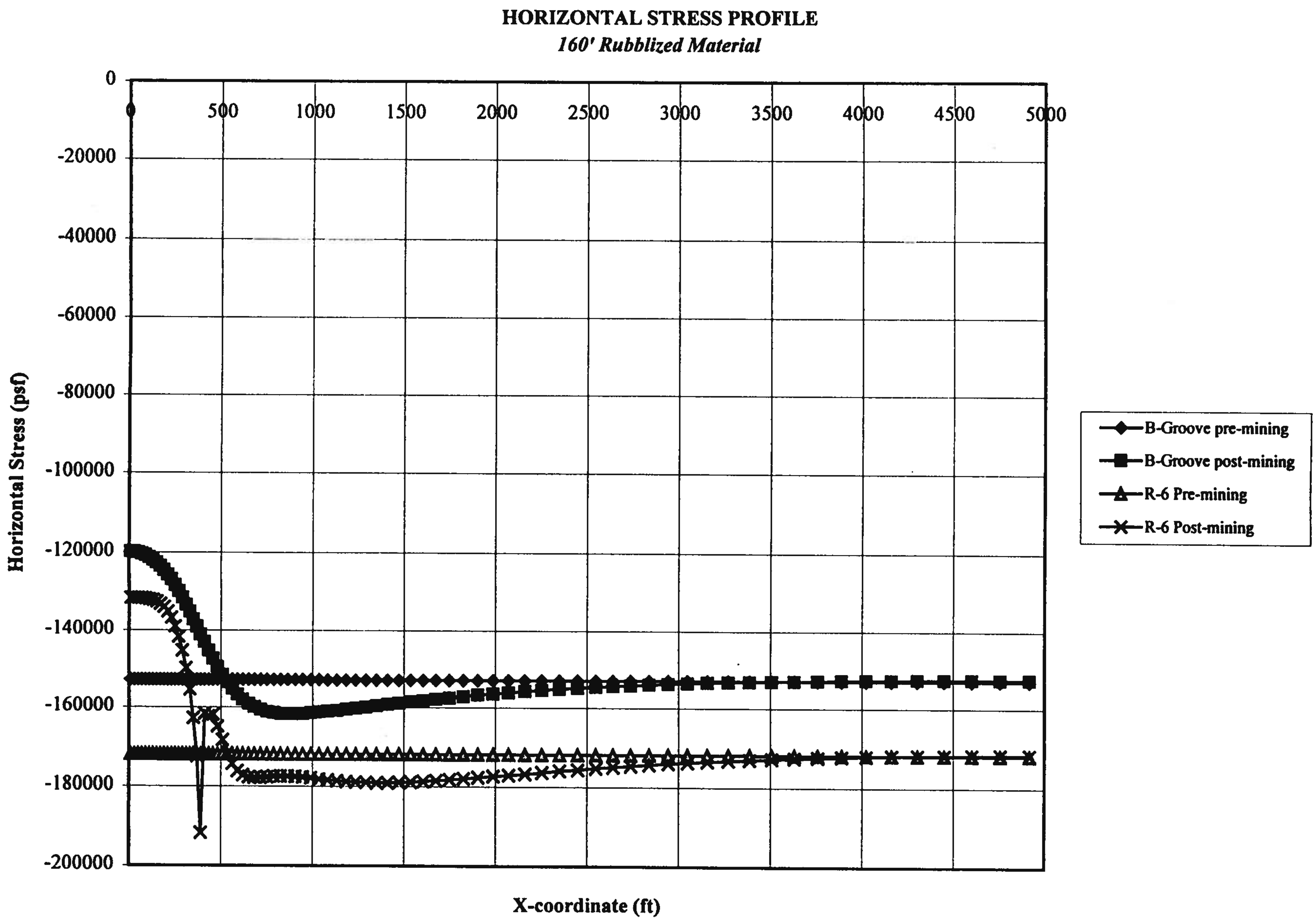

Figure C-3. Horizontal Stress Profiles for the 160-ft Caving Scenario

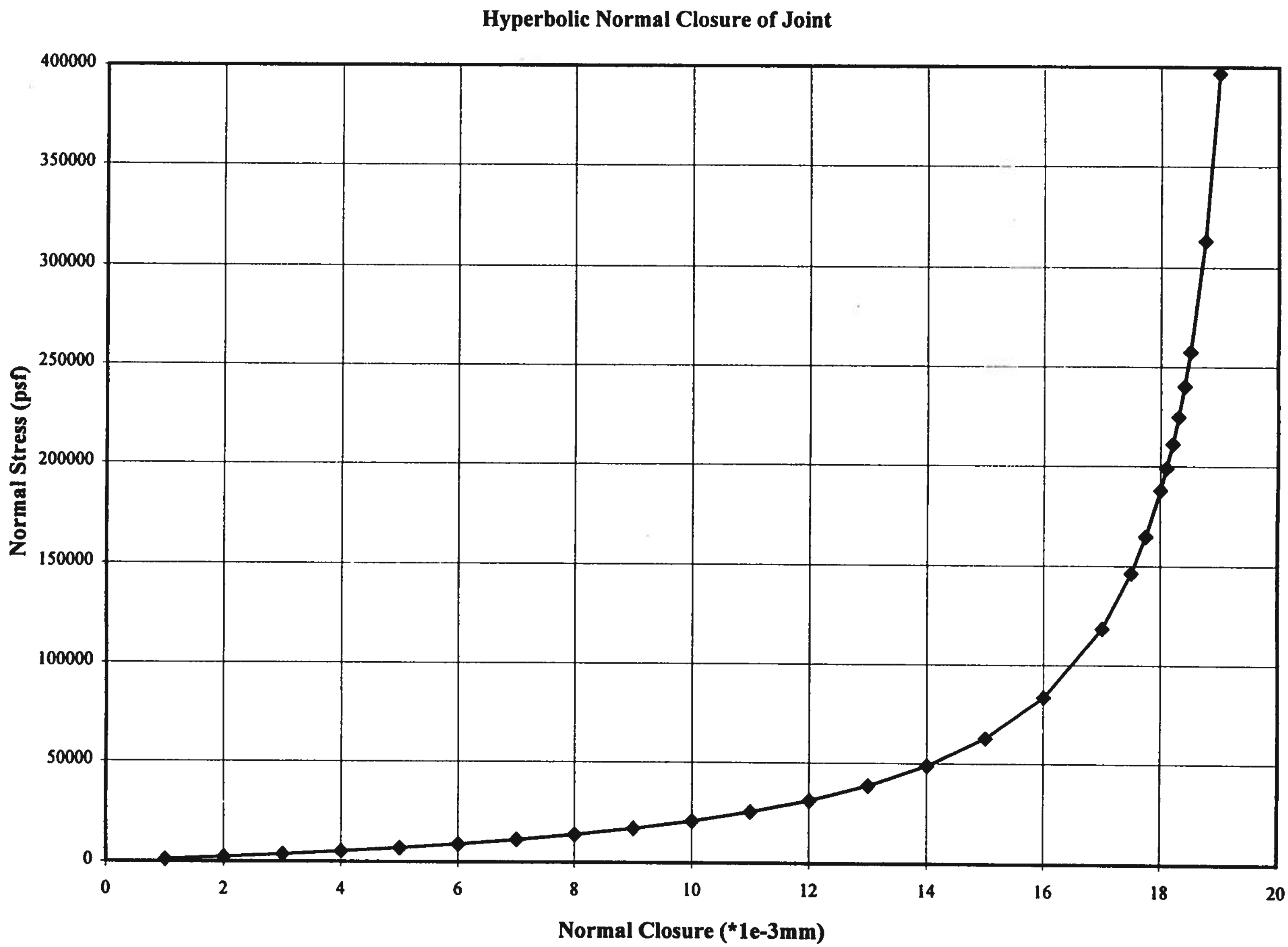

Figure C-4. Hyperbolic Normal Closure of Joint

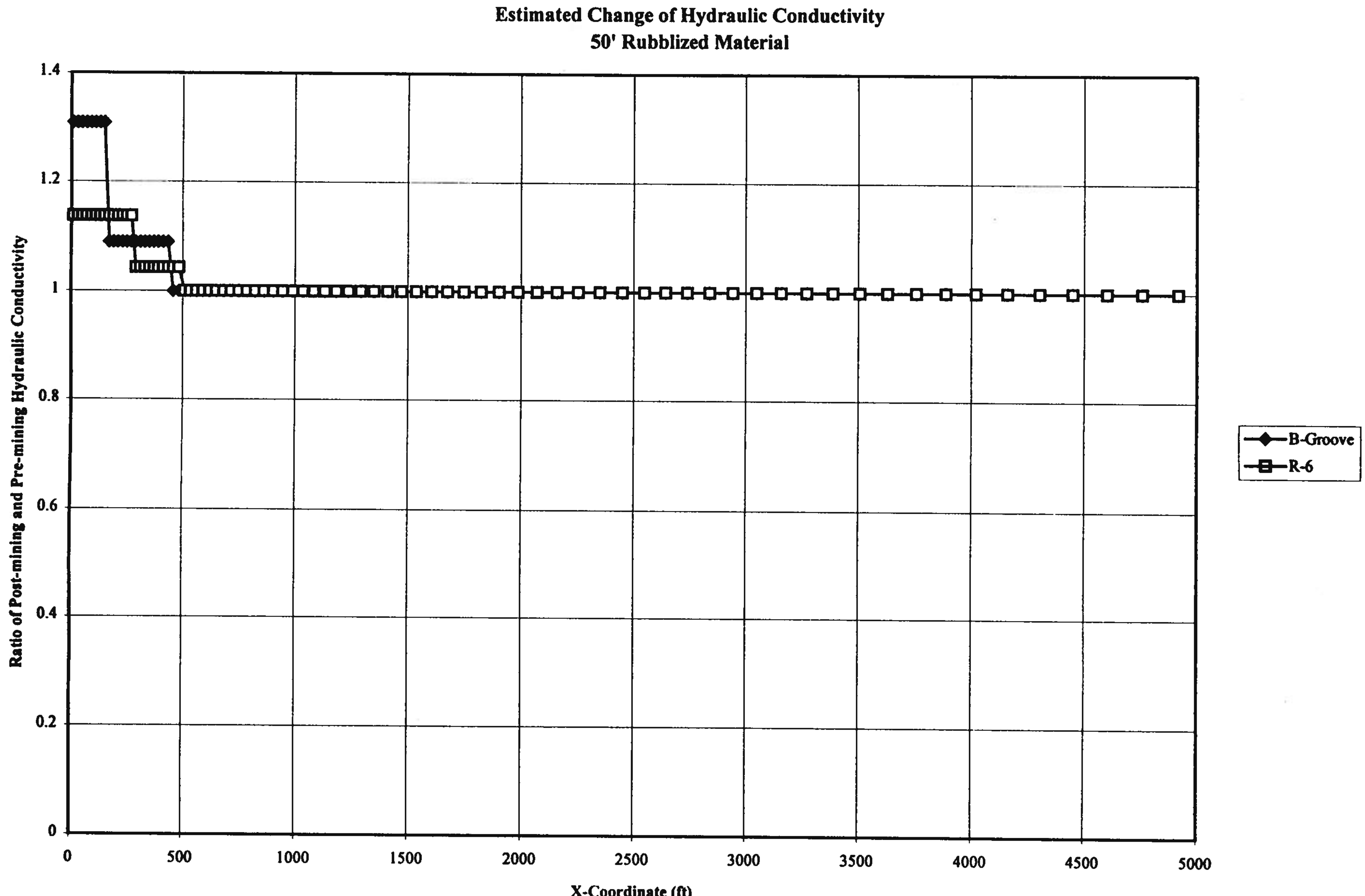

Figure C-5. Estimated Changes on Hydraulic Conductivities for the 50-ft Caving Scenario

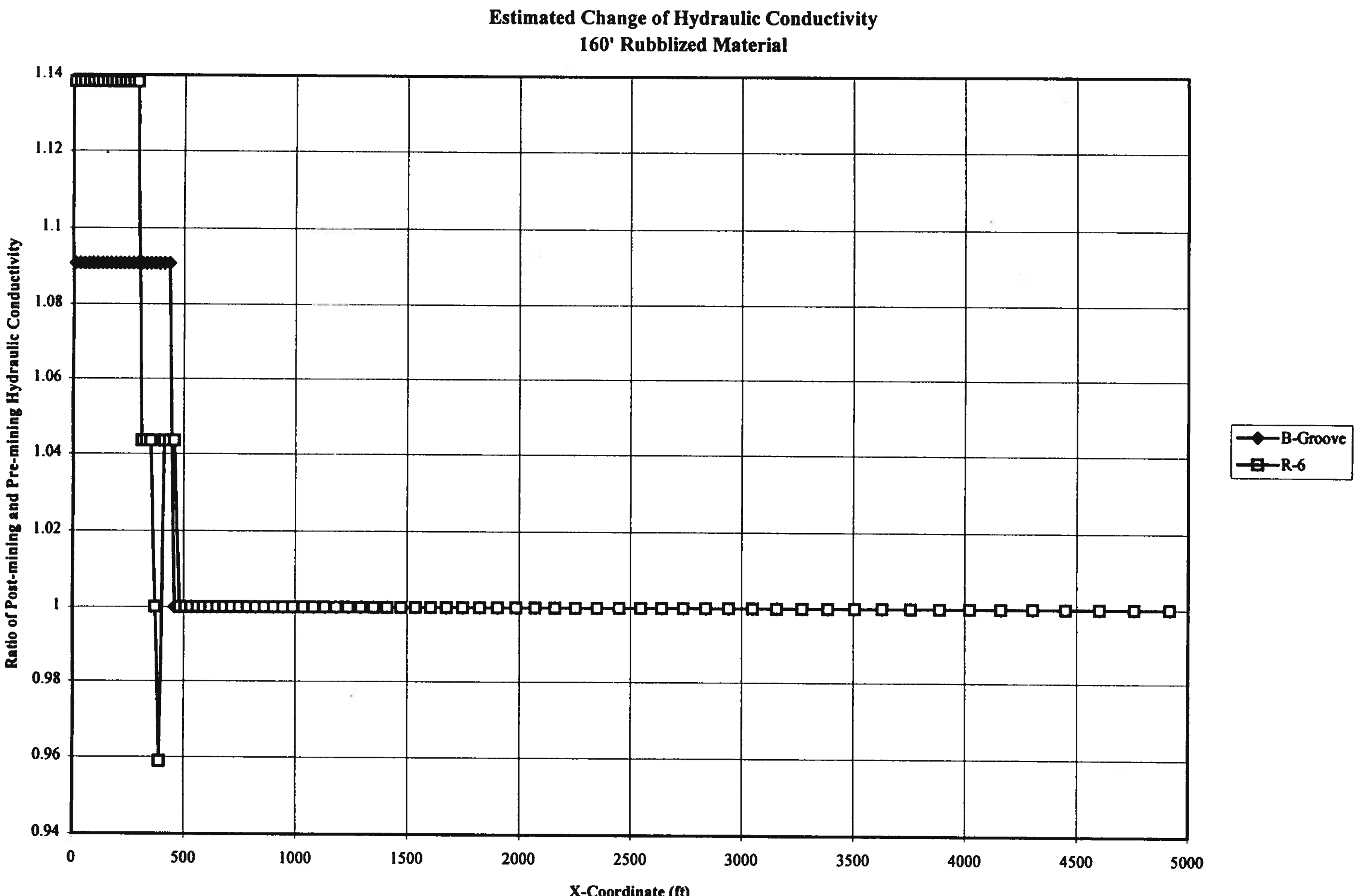

Figure C-6. Estimated Changes on Hydraulic Conductivities for the 160-ft Caving Scenario