HYDROGEOLOGIC CHARACTERIZATION
OF THE COLONY SHALE OIL PROJECT AREA

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ABSTRACT
Extensive geologic and hydrogeologic studies were conducted at the Colony Shale Oil Project site during the period 1980 to 1982. Geologic studies included stratigraphic, lithologic and geotechnical logging of 18 coreholes, extensive mapping of structural features, remote sensing analysis and a detailed interpretation of geologic and geotechnical data. Hydrogeologic studies involved the completion, testing and monitoring of 27 bedrock wells in 10 locations and 19 shallow bedrock and alluvial piezometers; infiltration testing and seismic refraction surveys. The programs were designed to gain information on both lateral and vertical hydrogeologic characteristics of the bedrock units, and the recharge potential of the surficial bedrock in the project area.

Data from these recent programs, previous work at the project site, continued monitoring and regional studies has been used to characterize the ground water system in this region of the Piceance Basin. Ground water movement is restricted almost entirely to secondary porosity features of the bedrock such as fractures, joints, partings, rubble zones, and nodule vug horizons. Vertical and lateral movement is also controlled by relatively continuous unfractured lithologic units and by sub-vertical sedimentary dikes. Ground water flow is influenced by secondary geologic features that are largely lithology dependent. The geomorphic character of the area has significant influence on the occurrence of recharge and discharge within the ground water system. Spring and seep location appears to be related to a combination of lithologic and structural controls. An assessment of potential hydrologic effects of the proposed mining and spent shale disposal operations at Colony may be made based on this hydrogeologic characterization.

INTRODUCTION
The Colony project is located at the headwaters of the Middle Fork of Parachute Creek in the southern part of the Piceance Basin (Figure 1). The development plan involves underground mining to extract a 60-foot thick zone of the richest oil shale known as the Mahogany zone. Retorting of the crushed oil shale rock will be conducted on the site and will produce a similar volume of relatively fine-grained spent shale. Disposal of the spent shale will be in small tributary valleys.

Detailed characterization of the surface and ground water regime in the area and an assessment of potential hydrologic effects are necessary for proper planning of the mining and spent shale disposal operations. Geologic and hydrogeologic studies have been performed in the area since the late 1960s. Extensive geologic and hydrogeologic studies were conducted at the Colony project site during the period 1980-1982. Certain data, such as water level and water quality in ground water monitoring wells, continues to be collected. The characterization of the hydrogeology of the Colony project area presented in this paper is based primarily on data obtained since 1980.
An extensive mapping program was conducted during the 1981 field season which included fracture mapping of natural outcrops and exposures on mine benches, road cuts and the coarse-ore conveyor tunnel; evaluation of previous mapping in the Colony pilot mine; and descriptions of special features such as nahcolite vug layers, tuff dikes, folds, springs and seeps. Ground mapping was augmented by remote sensing studies which employed air photographs and Landsat imagery.

Hydrogeologic Studies

During the 1981 field season a total of 24 wells were completed in seven locations for both monitoring and hydrologic testing purposes. Figure 2 shows the locations of the seven well sites, indicated by WW prefixes, and two coreholes which yielded significant hydrogeologic data. Many of the well sites coincided with corehole locations so that good geologic control was available.

Three of the seven sites (WW-6, WW-10, and WW-11) are locations of single wells completed directly above the proposed mine zone. The four remaining sites (WW-4, WW-5, WW-7, and WW-8) are locations in the proposed spent shale disposal area where several wells were installed. These wells were completed in specific bedrock intervals to allow examination of both vertical and lateral hydrogeologic characteristics. The WW-4 site includes 12 wells completed in six specific horizons (Figures 3 and 4). A detailed hydrogeologic testing program was conducted at this site during 1982.
The completion intervals for all monitoring wells were selected on the basis of geologic and hydrogeologic criteria and rarely exceeded 50 feet in length. The limited length of the completion intervals minimizes the possibility of intercepting stratigraphic units which have differing potentiometric and water quality characteristics. All wells were completed in individual holes using fiberglass casing with the open interval of the well usually drilled out after casing had been cemented in place. The exception to this practice was in the few cases of coreholes that were recompleted as wells.

Several field studies conducted during 1981 and 1982 were directed towards evaluating the near-surface hydrogeologic characteristics of the spent shale disposal area. These studies included seismic refraction surveys, infiltration testing, and a coring, well completion and testing program in the alluvium and shallow bedrock zones. Coring in the alluvium was performed at 19 sites with piezometers installed in 10 of the boreholes. Nine sites were cored in the shallow bedrock zones to depths ranging from 41 to 71 feet. Sites were located in ridge, slope and valley locations in order to identify geomorphic influences on fracture intensity and permeability. Piezometers were installed in all bedrock coreholes. Falling head hydrologic tests were performed on all alluvial and bedrock piezometers.

The results from all of the above studies have been evaluated together with data from continued monitoring of observation wells and information from studies in adjacent areas to formulate a reasonably detailed characterization of the ground water system in the vicinity of the Colony project area. This characterization was used as the basis for evaluating potential ground water inflow into the proposed mining operation and the effects of the Colony operation on the hydrologic regime.
The occurrence, movement and quality of ground water in the vicinity of the Colony project area is intimately associated with the lithologic and structural features of the regional geology. The topography of the area influences recharge and discharge characteristics of the ground water system and its relationship with the surface water hydrology.

**Geomorphology**

The Colony project area is drained by East Middle Fork and its tributaries (Coral Gulch, Spring Gulch, and Bear Cabin Gulch) and Middle Fork and its tributary (Davis Gulch). The northern boundary of the project area lies about 1 mile south of the topographic divide which separates the Piceance Creek drainage basin from the Parachute Creek drainage basin. Regional uplift during Pleistocene and Quaternary times has resulted in the southern parts of the Piceance Creek Basin being deeply incised. The canyons of East Middle Fork and West Fork form boundaries to the ground water flow system. Due to its location a large percentage of the land area outside of the main canyons and tributary valleys has an elevation of over 7500 feet above sea level.

**Stratigraphy and Rock Quality**

The stratigraphic formations exposed in the vicinity of the Colony project site include the Wasatch, Green River, and Uinta Formations. These formations reflect a transition from a fluvial environment (Wasatch) to a fresh water lake (Douglas Creek Member, Green River) to a closed saline lake (Parachute Creek Member, Green River) and finally freshwater lacustrine, deltaic and fluvial (Uinta) as the lake gradually filled with sediments. The boundary between the Green River and Uinta Formations is transitional, interfingering of clastic lithologic units of the Uinta with the fine-grained lacustrine deposits of the Green River is well documented in the literature (e.g. Roehl, 1974). The Parachute Creek Member of the Green River Formation and the Uinta Formation are of major significance to the hydrogeology (Figure 4).

The Parachute Creek Member of the Green River Formation has been divided into alternating rich (R) and lean (L) zones by Cashon and Donnell (1972). The richest oil shale zone in the Parachute Creek Member is known as the Mahogany zone or R7 zone. The mine plan for Colony calls for extracting a 60 ft (20 m) thickness of the Mahogany zone which has a total thickness of about 140 ft (46 m) in this area. Overlying the Mahogany zone is a lean zone, about 15 ft (5 m) thick, known as the A-groove or L7 zone. The base of this zone lies about 25 ft (8 m) above the proposed mine zone. Underlying the Mahogany zone is another prominent lean zone known as the B-groove or L6 zone. The B-groove is about 25 ft (8 m) thick in this area and the top of the unit occurs about 55 ft (38 m) below the base of the proposed mine zone.

The A-groove and the B-groove are generally highly fractured and exhibit low average rock quality designations (RQD) in core holes. These zones are less resistant to weathering and their outcrop expressions are usually indented, which led to the term groove, in stark contrast to the rich oil shale zones which stand out as ledges. The thickness and relatively unfractured nature of the Mahogany zone has led to the widely-held belief that this unit forms a major restriction to vertical ground water movement on a regional scale (Weeks et al., 1974; Robson and Saulnier, 1981). Conversely, the more prominent, highly fractured lean zones would be expected to provide conduits for lateral ground water flow.

The upper part of the Parachute Creek Member, above the A-groove, is generally referred to as the R8 zone. The lower 150 ft (45 m) of the R8 zone has moderate grade and RQD values. The lower R8 and the A-groove appear to be moderately well connected hydrologically and together form a hydro-stratigraphic unit which potentially would yield the majority of the ground water inflow into the proposed mining operation. Most of the impacts on the ground water system due to mine dewatering would be concentrated in this zone. The upper part of the R8 zone has a number of high grade zones known as the Four Senators, Stillwater, and Big Three. This section also exhibits generally high RQD values and over much of the project area is recognized as having significant potential for restricting the vertical movement of ground water. The location of the upper R8, just below the Uinta Formation, is significant since it appears to limit effective hydrological communication between the Uinta Formation and the Parachute Creek Member.

The richer oil shale horizons of the Parachute Creek Member are often associated with evaporite deposits, particularly nahcolite. Nahcolite is an amphoteric sodium bicarbonate, which led to the name, Nahcolite, that formed as nodules in the southern part of the Piceance Creek Basin and as bedded deposits in the evaporite facies in the central part of the basin. The nodular nahcolite in the Colony area has been almost entirely removed as a result of dissolution by circulating ground water, leaving cavities known as vugs. Nahcolite vugs exposed in mine bench faces and natural outcrop are conspicuously concentrated in lenticular layers which may be important as zones of active ground water flow and as locations of potential structural weakness. Correlation of nahcolite vug zones exposed in the mine bench face-up excavation with vugs intercepted during drilling identified eight significant horizons (Agapito and Associates, 1982). Percentage area of vugs in these horizons was measured on photographs and extrapolated to void volumes which range from 1,700 to 55,000 cubic feet per acre. Hydraulic continuity via partings is probable between vugs and vuggy lenses in the more prominent layers.

The Uinta Formation at the Colony project site consists of a sequence of sandstones and siltstone wedges intertonguing with lean marlstones and mudstones of lacustrine origin. The sequence reflects the transition from lacustrine to deltaic and lake margin deposition as the ancient lakes gradually decreased in size. The formation caps the present-day plateau and has a maximum thickness of 940 ft (310 m).

The Uinta Formation in the Colony area has been informally subdivided into units which are predominantly sandstone (S units) and those which are predominantly marlstones (M units) from detailed studies in the spent shale disposal area (Agapito and Associates, 1982). Five sandstone/marlstone paired units have been identified at Colony (Figure 5). All the upper marly units are relatively continuous across the property but have variable facies with lateral gradation between marlstone, marly siltstone, sandstone and shale lithologies. The basal S1 unit
contains thin, conformable, fine sandstone beds. The upper clastic units are massive or diffusely bedded sandstone or laminated siltstone-sandstone with occasional interbedded marly units.

The rock quality within the Uinta Formation is generally poor in the near-surface exposures as a result of stress relief fracturing and weathering. The marlstone units appear to be more highly fractured in outcrop than the sandstone/siltstone units but exhibit higher RQD values in cores. The apparent discrepancy is probably due to the thin bedding within the marlstone units which makes them more susceptible to stress-relief and weathering processes. The marlstone units appear to act as barriers to vertical ground water flow. Specifically, the M2 and M3 marlstone units exhibit good aquitard characteristics from the evidence that most springs in the area issue on the tops of these units and the observation of more dense vegetation at this stratigraphic position.

The S5 unit is typically the surface unit on the tops of ridges and shows weathering and oxidation to depths of up to 150 ft (44 m). The highly fractured nature of the surficial units, as observed in test pits, road cuts and cores, indicates a high infiltration potential. This was confirmed from infiltration testing and falling head tests on shallow bedrock piezometers.

Shallow coring and permeability testing at the Davis Gulch and Middle Fork Dam sites and the high productivity of a number of wells located in these creek areas has led to the inference that the shallow Uinta bedrock underlying these areas is highly fractured to depths of about 150 ft (44 m).

Structure

Structural data from drilling in the area indicates a general westward dip of lithologic units in the eastern part of the property. In the western part of the property structural data indicates a broad synclinal trough plunging to the NNW and SSE away from a saddle area between Davis Gulch and Middle Fork Creeks. The axial trends of this trough is roughly parallel to Davis Gulch.

Remote sensing studies were undertaken in conjunction with mapping studies in an attempt to define regional patterns possibly related to underlying rock structure or major structural discontinuities and to aid in delineating fracture sets (Agapito and Associates, 1982). The studies were also used to indicate the extent that fracture mapping patterns may be extrapolated from a narrow mapping base to the entire Colony property based on remotely sensed patterns. Lineaments mapped from enhanced Landsat imagery indicated six trends.

Drainage element analysis was undertaken over an area eight by thirteen miles, centered on the Colony property. Drainage patterns were analysed as length-weighted, near-linear watercourse elements divided into four orders. The drainage element analysis distinguished eight trends, six of which correlated with the six trends defined from Landsat imagery studies. The linear form of many of these creeks and the correlation with orientation of major lineaments tends to support the hypothesis that the creek areas may be structurally controlled.

The extensive mapping program conducted at the Colony property during the 1981 field season yielded fracture orientation data that could be classified into eight sets which correlate with the eight trends defined by drainage element analysis and remote sensing studies. Different fracture sets tended to dominate in the Parachute Creek Member of the Green River Formation and in the Uinta Formation. All sets have mean dips near vertical except for one set which contains conjugate fractures with mean dips around 55° to the north and south.

The spacing of the three most dominant fracture sets varies from 50-100 ft (15-30 m) to less than 2 ft (0.6 m) with zones of increased fracture intensity apparently forming lanes of lowered rock quality. The correlation of spring occurrence with lineaments identified from remote sensing studies indicates that they may be related to these zones of increased fracture intensity and higher relative permeability.

Other Geologic Features

Other geologic features have been observed to have significant influence on ground water flow patterns in the vicinity of the Colony project. Tuffaceous, sedimentary dikes having near-vertical dips may be observed in road cuts and mine bench exposures at several locations. They extend from lowest zones of the Parachute Creek Member to the base of the Uinta Formation. Their frequency and variation in strike may only be extrapolated from the Parachute Creek outcrops, but observation does not indicate any preferred strike orientation. The margins of some dikes have developed joints that may act as channels for ground water flow. The dikes themselves have the potential to impede ground water flow perpendicular to their strike since they are fine-grained in nature and have an observed low frequency of fracturing.

Several small folded structures were exposed in Middle Fork Canyon during construction activities. These structures exhibit similar characteristics, having abrupt buckles of one to two feet vertical offset and are downwarped to the west with crushed flexures one to two feet wide. The lateral extent and continuity of these structures cannot be gauged from the limited exposures. Their highly fractured nature indicates that they have a high potential for conducting ground water flow.

HYDROGEOLOGIC CHARACTERIZATION

The hydrogeology of the Colony Project area is influenced by a number of factors. Flow and storage within the ground water system is primarily controlled by the physical features of the geology. Other features such as geomorphology, vegetation cover, climatology and surface hydrology influence recharge and discharge characteristics of the flow system. Water quality is primarily influenced by the mineralogy of the bedrock units through which ground water passes and the prevailing chemical conditions.

The hydrogeologic characteristics of the major stratigraphic units have been described in the previous section. The following characterization attempts to relate the geologic and physical features of the area with data derived from hydrogeologic studies. The controls on ground water recharge, discharge and movement in the vicinity of the Colony project will be discussed and some conclusions on potential project development effects will be made based on these interpretations.
Recharge

The major source of recharge to the ground water system in the vicinity of the Colony project is believed to be snowmelt at elevations greater than 7500 feet. At these elevations snow is present on the land surface for up to six months of the year. The potential for infiltration of water into the subsurface is enhanced by an extended snow-melt period at a time when evapotranspiration is at a minimum. The Uinta Formation outcrops over most of the area above 7500 feet. Geologic and hydrologic studies indicate that the near-surface Uinta bedrock is highly fractured and has very high permeability and infiltration capacity. In addition, the majority of the area at this elevation has thin soil cover and sparse vegetation.

Good potential for recharge to the ground water system exists in the area of Uinta outcrop due to favourable climatic and geomorphic features. This contention is supported by potentiometric levels in non-valley areas which indicate a downward hydraulic gradient and by the existence of ground water mounds below topographic highs which infer that recharge is active in these areas (Figure 6). Certain lineaments identified from examination of satellite imagery, which may represent zones of increased fracture intensity, have the potential for allowing increased localized recharge to deeper stratigraphic units.

Other areas where recharge to the ground water system may be active are below the creeks via the alluvial deposits within the creek channels. Over most of the area, water levels in alluvial wells and in adjacent bedrock wells show downward hydraulic gradients, indicating the potential for influx of stream flow into the underlying bedrock. Water levels in alluvial wells and shallow bedrock wells respond markedly to variations in creek flows and the observation that many of the creeks within the Uinta Formation are losing streams indicates active recharge in these areas.

Climatological studies in the region indicate that the average annual precipitation is about 16 inches per year. About 40% of this precipitation, 6-7 inches (15-18 cm), is in the form of snowfall during the winter months. The remaining 60%, 9-10 inches (23-26 cm), occurs as rainfall, primarily in the form of thunderstorms during the summer months. Studies at the adjacent Naval Oil Shale Reserve (NOSR-1), which has a slightly higher average elevation, indicates a higher percentage of snowfall of about 65% (TRW, 1982). Water balance studies conducted at the Colony site and at NOSR-1 indicate an average annual ground water recharge rate of 0.6-1.1 inches (1.5-2.7 cm) per year.

Discharge

Discharge of the ground water system in the Colony project area is observed in the form of seeps and springs. A large proportion of discharge takes place in the form of evapotranspiration and is not directly observable.
Discharge in the form of springs occurs primarily in the Uinta Formation. Examination of mapped spring locations with respect to stratigraphic position and to lineaments identified from Landsat imagery shows that spring occurrence has strong lithologic and structural control. Most springs occur at the contacts of the S4/M3 or S3/M2 Uinta units described in the previous section and are on or adjacent to identified lineaments. Lineaments appear to be related to zones of more intense fracturing and increased permeability which may be more apparent in the sandstone/siltstone (S) units of the Uinta Formation. The marlstone units, particularly the M3 and M2 units, of the Uinta Formation are not as susceptible to fracturing and provide a restriction to vertical ground water flow. The combination of these two controls provides the necessary concentration of ground water flow to produce spring discharge at bedrock contact outcrops. In the absence of fracture control, discharge tends to occur as diffuse seepage along the S4/M3 and S3/M2 contacts which is often recognized due to a concentration of vegetative growth at these levels.

Ground water discharge may be observed in the form of seeps in outcrops of the Parachute Creek Member of the Green River Formation. In general, seepage occurrence is patchy but usually is related to geologic conditions. Most seeps are observed to issue from vuggy horizons, significant bedding plane partings and silty or highly fractured zones such as the A- and B-grooves. Seeps are also related to vertical joints and dike margins which provide conduits for vertical and lateral ground water flow. Tuff dikes which are composed of tight siltstone appear to form restrictions to lateral flow. Seep occurrences are often related to these features in part due to a concentration of flow, parallel to and behind them.

Ground Water Flow Systems

Ground water flow in the bedrock units of the Colony project is controlled primarily by lithologic and structural features. Flow directions within the ground water system are also influenced by the location of recharge and discharge areas which in turn are largely determined by topographic features.

The major source of recharge for the Uinta Formation is from snowmelt at elevations above 7500 feet. Water that enters the subsurface at these elevations and infiltrates below the root zone moves under the influence of gravity until it reaches a zone of saturation. Since the stratiographically higher units of the Uinta (S5,M6 and S4) do not have any significant lithologic horizons that impede vertical flow, the ground water system is in an unsaturated condition. Flow in the unsaturated zone is primarily vertical although actual flow paths are controlled by fracture occurrence.

The highest stratigraphic unit within the Uinta which has the characteristics to significantly impede vertical flow is the M3 marlstone unit. The restriction of flow above this unit results in perched saturated ground water conditions and significant lateral components of flow at or just above this stratigraphic level. The highest level of spring discharge coincides with this stratigraphic interval. Water levels in drill holes are often observed to drop as the M3 unit is penetrated which is consistent with the inferred low permeability of this unit.

The M2 Uinta unit has similar low permeability characteristics as the M3 unit. Saturated zones are supported above this unit due to increased resistance to vertical ground water flow. Lateral flow components also tend to be concentrated above the M2 unit leading to increased instances of ground water discharge in the outcrop areas at the contact between the M2 and the overlying S3 unit. Perched conditions above the M2 may exist, particularly close to canyon areas, but fully saturated, confined conditions are usually encountered from this level down through the Parachute Creek Member.

The highly dissected topography in this area strongly influences a fairly localized and relatively active ground water flow regime in the Uinta Formation. A large proportion of the recharge which occurs in the ridge areas discharges after relatively short flow paths in the form of springs or by evapotranspiration on valley sides at the M3 and M2 stratigraphic levels. There are very few areas in the plateau region where lateral ground water flow will not encounter a potential discharge zone in a valley within a relatively short distance. Consequently, the potential recharge to the underlying Parachute Creek Member is significantly reduced.

A component of downward flow exists throughout the area and a certain amount of recharge to the Parachute Creek Member does occur through vertical fractures. The significant potentiometric drop observed in nested wells completed at various stratigraphic intervals in the ridge areas indicates that the vertical hydraulic continuity is generally poor. Given the large surface area available for vertical leakage, a very low rate of vertical flow can result in a significant volume of recharge to lower bedrock units. The potential for recharge is significantly increased in areas of more intense vertical fracturing which may be associated with lineaments identified from Landsat imagery.

The spring discharges from the Uinta Formation form the primary source of surface water flows in the major creeks draining the plateau area. Much of this flow may be lost to the bedrock underlying the creeks, via the valley alluvium, downstream from the springs. Most of the water that infiltrates into the subsurface below the creeks remains effectively as shallow underflow and may again reappear as surface flow where the creeks cut across more resistant bedrock units.

The creek areas are potentially very significant as recharge zones for the underlying bedrock units of the Parachute Creek Member where there is evidence of relatively good vertical hydraulic communication compared to the ridge areas. This evidence includes the observation that potentiometric levels do not vary appreciably with depth, high productivities of wells completed in valleys and direct and indirect indications that the creek areas may coincide with zones of increased fracture intensity.

Most of the recharge to the Parachute Creek Member is derived from vertical leakage from the Uinta Formation primarily in the ridge areas. This contention is supported by the configuration of the potentiometric surface for the A-groove zone (Figure 6) which is a subdued reflection of the overlying surface topography. This indicates that ground water flow tends to move from ridge areas to valley areas. In the valleys both vertical flow and lateral flow parallel to the valley direction occurs. Actual flow paths for ground water are determined by the
occurrence and configuration of secondary porosity features of the bedrock. The apparent high transmissivity of the shallow bedrock zones underlying the valleys result in localized active flow regimes. Discharge of ground water to surface streams only tends to occur at points where the streams cut down to resistant bedrock, such as the Mahogany zone, which inhibit vertical flow.

Ground water flow within the Parachute Creek Member is predominately lateral as the bedrock is characterized by geologic features that follow the structural dip and tend to enhance permeabilities in this direction. Even though vertical fractures and joints predominate throughout the bedrock sequence, below the zone of saturation these vertical features do not preclude lateral ground water movement parallel to the fracture or joint planes.

The upper part of the R8 zone and the Mahogany zone are two important hydrostratigraphic units that restrict the vertical movement of ground water in the Parachute Creek Member. Potentiometric drops across these units, particularly in the ridge areas, are appreciable, which indicates the low permeability of these units. As in the Uinta Formation potentiometric differences indicate a greater degree of hydraulic communication in valleys as opposed to ridge areas. Water level variation and water quality data from wells completed above and below the Mahogany zone also indicate poor hydraulic connection across this unit. Static water levels in drill holes are usually observed to drop appreciably when the Mahogany zone is penetrated. While there are several indications that the vertical permeability of the Mahogany zone is generally low and it exhibits very good aquitard characteristics, ground water flow across the zone does occur primarily through discrete fractures. Throughout the area there is almost invariably a downward hydraulic gradient across the Mahogany zone so that the potential for downward vertical ground water flow exists. Due to the large area available for vertical flow the total volume of flow is significant even under very low flow rates.

The upper R8 zone exhibits similar characteristics to the Mahogany zone, although it is not as effective an aquitard on a regional scale. In addition to evidence based on water level variations in wells, and relatively good rock quality characteristics, two other significant observations were made during the drilling of the CD-23 and CD-32 coreholes (Figure 2).

Ground water was encountered under significant confined pressure in the CD-23 corehole after penetration of the upper R8 zone. Above this zone the corehole had been essentially dry. The CD-32 corehole located just east of the Colony pilot mine encountered saturated ground water at the base of the Uinta Formation. Static water levels taken on a daily basis as the hole advanced indicated a steady drop through the lower Uinta and the upper R8 zone. At a point about 100 ft (30 m) above the mine zone the water in the drillhole drained completely and remained dry until the hole penetrated the B-groove (Figure 7).

The water level variation encountered in the CD-32 hole indicates that the zone to about 100 ft (30 m) above the Colony pilot mine has been effectively dewatered by drainage into the mine over the past 15 years. An effective drawdown of over 250 ft (80 m) in this zone has not had any appreciable effects on water levels within and above the upper R8 zone. This indicates that the upper R8 is an effective aquitard which prevents significant vertical hydraulic communication.

Water Quality

Interpretations of ground water quality are based on data collected since the initiation of formalized sampling procedures in 1981. Water quality data collected prior to this time are not as reliable since sampling procedures were not as well defined. Ground water quality in the Uinta Formation is characterized by a calcium-bicarbonate type or mixed-cation-bicarbonate type in areas of recharge which results primarily from reaction of slightly acidic precipitation with the carbonate cements of the Uinta bedrock. There is a tendency for increased sodium content and decreased calcium content with increased contact with the Uinta bedrock as a result of calcite precipitation, ion exchange and interactions with organic rich lithologic units. Robson and Saulnier (1981) found similar results on a regional basis for the Piceance Creek Basin.

Almost all water quality samples obtained from wells completed in the Parachute Creek Member exhibit sodium-bicarbonate dominance. This is true of wells completed above and below the Mahogany Zone. Samples collected from two roof seeps in the Colony pilot mine also exhibit similar characteristics. Total dissolved solids tend to be higher in Parachute Creek ground waters than in Uinta ground waters due mainly to the significantly higher sodium and bicarbonate contents. The increased sodium content is most probably the result of nahcolite dissolution. Fluoride concentrations are characteristically high, ranging from 1.1 to 16.1 mg/l. The high fluoride concentrations indicate some mineral dissolution or exchange and the low calcium concentrations allow fluoride to stay in solution. The distribution of dissolved fluoride is theoretically related to the solubility product of fluorite (CaF2). The absence of significant concentrations of fluoride in the Uinta Formation is due primarily to the high calcium concentrations.

![Figure 7: Water Level Variation with Depth for CD-32 Corehole](image-url)
POTENTIAL HYDROLOGIC EFFECTS OF THE COLONY OPERATION

Some general conclusions may be drawn regarding potential hydrologic effects of development on the basis of the hydrogeologic characterization described above. Over much of the project area significant hydraulic pressures presently exist in the vicinity of the proposed mine zone. In general, natural mine drainage should be sufficient to effectively reduce the ground water pressures in the bedrock units directly overlying the mine zone to acceptably safe levels within a short period of time after mining of any given area. Induced depressurization, using pressure relief holes or other methods may be required in areas of high bedrock permeability and storage such as the canyon areas. These areas also have the greatest potential for significant mine inflows.

The planned reservoirs in Davis Gulch and Middle Fork lie above the proposed mine zone and will enhance the potential for higher mine inflows due to increased vertical hydraulic gradients, increased fracture permeability under the higher bedrock pore pressures and the existence of a large recharge source. Further work is planned to quantify the potential effects of the reservoirs; it is not believed, however, that they would pose any significant problem to the mining operation.

Water level drawdown effects due to mine dewatering generally will be restricted to the bedrock units within about 200 feet of the mine roof. Drawdown effects should not significantly influence stratigraphically higher zones such as the Uinta Formation except in areas of high vertical conductivity which may exist in the canyon areas. Most of the springs issuing from the Uinta Formation in the area should not be significantly effected. Since these provide most of the surface water flow in the headwaters of the major drainages these flows should not be significantly impacted.

The potential impacts of spent shale disposal on the hydrologic system are influenced by the mechanical and hydraulic properties of the spent shale and the procedures adopted for moisturizing and compacting of the material during the disposal operation. Control of moisture content and compactive effort during the construction of the disposal pile may be necessary to ensure pile stability and to minimize the potential for ground water contamination due to leachate drainage.

If drainage of leachates from the disposal piles does occur, the shallow ground water flow system in the Uinta Formation could possibly be affected since the surficial bedrock in the disposal area is highly fractured and there is little potential for retardation of leachates. Detailed hydrogeologic studies in the spent shale disposal area identified two significant bedrock units that have favourable characteristics for minimizing vertical movement of contaminated ground water to deeper bedrock zones. The studies also indicate that the shallow ground water system in this area is relatively localized, with flows tending toward the Davis Gulch area.

Studies of the behaviour of the spent shale under various moisturizing and compaction conditions will be used to design disposal operating procedures to minimize the drainage of leachates from the disposal piles. Recognition of the hydrogeologic features of the disposal area will allow an adequate program to be designed for monitoring water quality and containing any ground water that may become contaminated within the immediate area of the disposal piles.

REFERENCES


Cashion and Donnell, 1972, Chart showing correlation of selected key units in the organic-rich sequence of the Green River Formation, Piceance Creek Basin, Colorado and Uinta Basin, Utah. USGS Oil and Gas Inv. Chart OC-65


