NON-TRIBUTARY GROUND-WATER STUDY
ROCKY FLATS PLANT

Task 29
of the
Zero-Offsite Water-Discharge Study

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NON-TRIBUTARY GROUND-WATER STUDY
ROCKY FLATS PLANT

EXECUTIVE SUMMARY

This report has been prepared for one of several studies being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle (AIP) between the Colorado Department of Health (CDH) and the U. S. Department of Energy (DOE) (DOE and State of Colorado, 1989). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharge Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review" (AIP, p. 8).

This non-tributary ground-water study assessed the physical and economic feasibility of pumping non-tributary ground water from beneath the RFP to replace stored or diverted surface water and tributary ground water, for use as makeup/dilution water, or augmentation/substitute supply water for injured water rights. Ground water underlying the RFP in the Arapahoe and Laramie-Fox Hills aquifers is considered to be the property of the overlying land owner, unless consent has been given by the landowner, either express or implied, to the withdrawal of the water from that aquifer by another.

Augmentation or replacement water will most likely be needed to replace STP effluent that would be recycled (up to 237 ac-ft annually). Water would also be needed to augment surface-water runoff detained on site (between 110 and 233 ac-ft annually), as well as tributary ground water diverted out of priority (about 10 ac-ft annually). Depending upon the selected zero-discharge alternative, between 120 and 480 ac-ft of augmentation or replacement water could be needed to offset stream depletions.

In order to assess the feasibility of withdrawing water from the Laramie-Fox Hills aquifer to use as potential replacement or augmentation water for zero discharge alternatives, an analysis of a hypothetical wellfield at the RFP was undertaken. Drawdowns in individual wells in the wellfield and at selected locations between wells were calculated using the Theis equation and superposition. Based upon hydraulic characteristics of the Laramie-Fox Hills aquifer, drawdowns were calculated assuming that the aquifer was of infinite areal extent, had an initial potentiometric surface 700 ft above the top of the aquifer (confined). Drawdowns in excess of 700 ft would indicate that withdrawal of water at the indicated pumping rate or well spacing was not feasible.

Results of the drawdown analysis indicated that between 40 and 50 ac-ft annually could be withdrawn from non-tributary ground water underlying the RFP. This quantity is not enough to offset the estimated 120 ac-ft to 480 ac-ft of augmentation or replacement water needed under zero-discharge alternatives. Therefore, another source of augmentation or replacement water is needed. This other source could be lease water from an existing Denver basin water user who has excess water and would be willing to provide it to the RFP. There is generally no guarantee that the lease water would be available when needed and the leases are usually of short duration (2 to 5 years).

The cases used to estimate non-tributary water withdrawal costs consisted of between 3 and 8 wells, 1120-ft deep, pumping 10 gpm; a transmissivity of 50 gpd/ft; a storativity of 2×10^{-4}; and a 4000-ft well spacing. Annual costs of non-tributary water for annual withdrawals ranging from 10 to 50 ac-ft/yr varied from $1,325/ac-ft to $2,600/ac-ft to bring water from the Laramie-Fox Hills aquifer and transport it 1 mile to a point of use. Lease of water from Coors with discharge into Clear Creek or the South Platte River to meet South Platte River calls would have an annual cost of about $300/ac-ft. Based upon the analysis of non-tributary ground-water at the RFP, it would be less expensive to lease water for replacement or augmentation of downstream water diverted out of priority under zero discharge than to develop on-site Laramie-Fox Hills aquifer water.

NON-TRIBUTARY GROUND-WATER STUDY
ROCKY FLATS PLANT

1.0 INTRODUCTION

1.1 BACKGROUND

This report has been prepared for one of several studies (ASI, 1990a) being conducted for, and in the development of, a Zero-Offsite Water-Discharge Plan for Rocky Flats Plant (RFP) in response to Item C.7 of the Agreement in Principle (AIP) between the Colorado Department of Health (CDH) and the U. S. Department of Energy (DOE) (DOE and State of Colorado, 1989). The CDH/DOE Agreement Item C.7 states "Source Reduction and Zero Discharge Study: Conduct a study of all available methods to eliminate Rocky Flats discharges to the environment including surface waters and ground water. This review should include a source reduction review" (AIP, p. 8).

1.2 SCOPE AND PURPOSE

This non-tributary ground-water study assesses the physical and economic feasibility of pumping non-tributary ground water from beneath the RFP to replace stored or diverted surface water and tributary ground water, for use as makeup/dilution water, or augmentation/substitute supply water for potentially injured water rights (ASI, 1990b and c). Ground water underlying the RFP in the Arapahoe and Laramie-Fox Hills aquifers is considered to be the property of the overlying land owner, unless consent has been given by the landowner, either express or implied, to the withdrawal of the water from that aquifer by another (Colorado Revised Statues, 1973, Supp. 1989). Contrary to the general rule that water rights are unrelated to ownership of the land on or under which they are located, the initial right to the water in the Denver basin aquifers, including the Arapahoe and Laramie-Fox Hills aquifers, derives directly from land ownership (Holland & Hart, Attorneys at Law, 1990). The rationale for this distinction is the fact that the

withdrawal of water from these aquifers has little effect on surface streams or tributary ground water and that recharge to the aquifers is minimal, causing withdrawal of the water to be equivalent to the extraction of a mineral.

The Colorado State Engineer has determined that much of the water in Denver basin bedrock aquifers underlying the RFP is not tributary to surface streams (VanSlyke and others, 1988a-d). Therefore, this water may be put to beneficial use, under certain constraints, without the need to augment surface-water rights. Additionally, this water may be used to extinction, because return flows are not at issue. Information on the extent of non-tributary ground water in the Denver basin and in the vicinity of the RFP may be found in VanSlyke and others (1988a-d). These references were used to estimate the quantity of non-tributary ground water beneath the RFP and also to estimate the rate of withdrawal of the non-tributary ground water which could serve as augmentation water to offset potential injury to senior water rights as a result of implementation of a zero-discharge plan (ASI, 1990a).

As part of this analyses, the costs of construction and pumping non-tributary ground water from beneath the RFP has been estimated for comparison with the cost of leasing water from nearby surface-water sources. The leasing case should include the availability of water during a dry year or series of dry years. A hypothetical on-site wellfield was assumed along with hypothetical ground-water withdrawals based upon the amount of augmentation or replacement water required as a result of implementation of a zero-discharge plan. A range of important hydrologic and hydraulic variables (specifically, aquifer transmissivity and storativity, potentiometric surface, and wellfield flow rates and drawdowns) was assessed in order to give a parametric view of the possible costs of wellfield implementation. Plots of water withdrawal versus costs were developed to compare with a surface-water lease option for obtaining appropriate quantities of augmentation or replacement water.

Because the actual zero-discharge plan for the RFP has not been formulated at the time of this study, the target quantities of replacement or augmentation water presented here are generalized.

Because this report was prepared without benefit of legal counsel, the details of this study may be insufficient for water rights engineering for Colorado Water Court. Where possible, water-rights legal opinions from previous studies (ASI, 1990a; DOE, 1991) have been included.

Other studies that are subordinate to the Zero-Offsite Water-Discharge Plan that will be affected by or will affect this task may include, but not necessarily be limited to: Surface-Water and Ground-Water Rights Study (Task 14) (ASI, 1991a); Feasibility of Ground-Water Cutoff/Diversion Study (Task 26) (ASI, 1991b); Augmentation Plan for the Rocky Flats Plant (Task 28) (ASI, 1991c); and Consolidation and Zero Discharge Plan (Task 30) (ASI, 1991d). Input from these subordinate tasks which have been initiated were used in this study where appropriate.

2.0 REPLACEMENT OR AUGMENTATION WATER QUANTITIES

The Task 14 study (Surface-Water and Ground-Water Rights Study, ASI, 1991a) assessed the hydrologic characteristics of streams and aquifers in the vicinity of the RFP. The purpose of that assessment was to give a preliminary analysis of potential injury to both surface-water and ground-water rights downstream from the RFP for various preferred alternatives related to zero-offsite water discharge from the RFP and for alternatives to zero discharge from the RFP such as on-site irrigation of pasture grass, off-site irrigation of landscaping at the new Denver airport, or off-site water reuse at the Denver Water Department Potable Reuse Plant.

Results of the Task 14 study (ASI, 1991a) indicated that the RFP may have to replace up to 237 acre-feet per year (ac-ft/yr) from recycle of Sewage Treatment Plant (STP) effluent which currently is treated and released to Walnut Creek. However, previous correspondence between the Denver Water Board (DBW) and DOE (Rockwell International, 1977; DWB, 1978; DOE, 1978) indicates that the replacement of STP effluent may not be required. Permission should to be obtained from the DWB prior to assuming that the STP effluent could be used to extinction (Holme, Roberts and Owen, Attorneys at Law, 1990). A possible worst case would be that the RFP would have to provide augmentation or replacement water for the total average annual STP effluent volume of 237 ac-ft.

Surface-water runoff augmentation or replacement water volumes also were estimated in the Task 14 study (ASI, 1991a). Based upon dry-year South Platte River call data obtained from the Colorado State Engineer's Office, between 110 ac-ft and 233 ac-ft of water may have to be replaced annually depending upon the zero-discharge alternative selected. The quantity of ground water which may have to be replaced or augmented is unknown at this time, but has been assumed to be on the order of 10 ac-ft/yr (DOE, 1991).

Thus, the total estimated annual quantity of augmentation or replacement water for various preferred zero-discharge options and alternatives to zero discharge may vary from 120 ac-ft to

480 ac-ft depending upon the zero-discharge alternative selected for the Zero-Offsite Water-Discharge Plan. DOE (1991) estimated that annual augmentation or replacement water volumes may range from 220 ac-ft to 500 ac-ft during a dry runoff year, and between 260 ac-ft and 540 ac-ft during an average runoff year. These value, however, were for generally larger drainage areas than were used in the zero-discharge studies.

3.0 NON-TRIBUTARY GROUND WATER BENEATH ROCKY FLATS PLANT

3.1 HYDROGEOLOGIC SETTING

The RFP is located four miles (mi) east of the Front Range section of the Southern Rocky Mountain province and along the western margin of the Colorado Piedmont section of the Great Plains physiographic province (Spencer, 1961). The RFP is located on a pediment alluvium that dips approximately one degree to the east and is dissected by several small streams that flow eastward with their headwaters either on, or one to two mi west of the RFP.

The stratigraphic section in the vicinity of the RFP extends from Precambrian to the Quaternary. Figure 1 represents the stratigraphic section specific to the RFP. Because of the erosion of a large Laramide monoclinal fold, the sequence of rocks from the Pennsylvanian/Permian Fountain Formation to the late Cretaceous Arapahoe Formation crops out west of the RFP. The strata that crop out at the RFP and directly underlie the RFP are, from oldest to youngest (Figure 1), the Pierre Shale, Fox Hills Sandstone, Laramie Formation, and Arapahoe Formation. This stratigraphic sequence represents a continuous transition from a fluvial depositional facies through a deltaic environment to a marine depositional facies (EG&G Rocky Flats, Inc., 1991). Table 1 is a summary of the formations, thicknesses, and facies that occur in the upper portion of the stratigraphic section present at the RFP. These thickness do not necessarily agree with previously published data by VanSlyke, and others (1988c and d) on the Arapahoe and Laramie-Fox Hills aquifers. Following are descriptions of each of the formations in Table 1.

Recent preliminary information from EG&G (J. W. Langman, Jr., personal communication) indicates that the previous geologic characterization of the bedrock aquifers at the RFP are being revised. It appears that units underlying the RFP which were previously identified as the Arapahoe Formation actually may be part of the Laramie Formation. Because a new geologic characterization has not yet been completed at the RFP, this report uses existing published information and data related to the bedrock aquifers. Additionally, the geologic characteristics

Table 1

Summary of Formations at RFP

Formation	Thickness (ft)	Facies
Rocky Flats Alluvium	10 - 100	Alluvial Fan
Lower Arapahoe Formation	250	Fluvial (meanders at top, braided at base)
Laramie Formation	692	Deltaic (Distributary and paludal)
Fox Hills Sandstone	75	Delta - Front
Pierre Shale	>8,000	Marine

Source: EG&G, Rocky Flats, Inc., 1991.

at the RFP compiled by EG&G Rocky Flats, Inc. (1990, 1991) may vary from extrapolations and interpolations taken from U. S. Geological Survey (USGS) publications. Generally, the EG&G data are more reliable because they represent on-site investigations, whereas, the USGS data are from wells outside the RFP boundary.

3.2 HYDROLOGY OF THE BEDROCK AQUIFERS

The bedrock aquifers at the RFP include the Pierre Shale, Laramie Formation-Fox Hills Sandstone, and the Arapahoe Formation. The Laramie-Fox Hills and Arapahoe are known to yield moderate amounts of water to wells in the Denver basin. The Pierre Shale is not considered to be an aquifer in the Denver basin.

3.2.1 Pierre Shale

The Pierre Shale is over 8,000 feet (ft) thick and is predominantly a medium to dark gray, non-calcareous montmorillonite shale. It contains forminifera and *Baculites clinolobatus*, an ammonite, indicating that the Pierre Shale was deposited in a marine environment. The contact between the Pierre Shale and the Fox Hills Sandstone is complex because it represents the transition between marine and continental rocks. Figure 2 shows the approximate contact between the Pierre Shale and the overlying Fox Hills Sandstone on the RFP. No water wells are known to be completed in or penetrate the Pierre Shale in the vicinity of the RFP.

3.2.2 Laramie Formation-Fox Hills Sandstone

The Fox Hills sandstone is approximately 75 ft thick (Figures 1 and 3) and is a grayish-orange to light gray calcareous, fine grained, subrounded, friable, glauconitic, felspathic sandstone with thin beds of siltstone and claystone. Weimer (1976) interpreted the Fox Hills delta-front sandstone that exists as a separate facies with the underlying Pierre Shale and the overlying Laramie Formation. Figure 2 shows the approximate location of the geologic contact between

the Pierre Shale and the Fox Hills sandstone as well as the approximate location of the geologic contact between the Fox Hills Sandstone and the Laramie Formation at the RFP (Spencer, 1961; Van Horn, 1972).

The Laramie Formation is about 700 ft thick (Figures 1 and 3) and is composed of a lower sandstone/coal interval and an upper claystone interval. The sandstones are light to medium gray, fine to coarse grained, poorly to moderately sorted, subangular, silty, quartzitic, and contain grains of black chert, clay mica, and carbonaceous material (Van Horn, 1957, 1972; Weimer, 1976). The claystones are kaolinitic and are light to medium gray with lesser amounts of dark gray to black carbonaceous claystone (Weimer, 1976).

The estimated water in storage beneath the RFP in the Laramie-Fox Hills aquifer was estimated by EG&G Rocky Flats, Inc. (1991). Table 2 shows the estimated quantity of water stored in the Laramie-Fox Hills aquifer beneath the RFP plant boundary as shown on Figure 2. The average thickness of the Laramie-Fox Hills aquifer was estimated from isopach maps given by VanSlyke and others (1988d). The average saturated thickness and porosity of the Laramie-Fox Hills aquifer at the RFP were estimated by EG&G Rocky Flats, Inc. (1991). Approximately 228,600 ac-ft of water is estimated to be in storage in the Laramie-Fox Hills aquifer beneath the RFP assuming an area of 6350 ac, a saturated thickness of 120 ft and a porosity of 30 percent.

The Colorado State Engineer will permit the overlying landowners, or those with control of the land surface overlying non-tributary ground water to beneficially use the ground water at a rate which would deplete the resource in 100 years, or a withdrawal rate of one percent of the non-tributary ground water per year. According to interpretation of the Colorado State Engineer's maps of the Laramie-Fox Hills Aquifer at the RFP (VanSlyke and others, 1988d), all the Laramie-Fox Hills aquifer underlying the RFP is considered by the Colorado State Engineer to be non-tributary. Withdrawal in excess of one percent per year is allowed pursuant to a "banking provision" so long as the total volume of water withdrawn does not exceed the product of the number of years since the date of issuance of the appropriate well permit or the date of

Table 2

Estimated Ground Water in Storage Beneath RFP

Aquifer	Area (ac)	Average Thickness (ft)	Average Saturated Thickness (ft)	Porosity[1] (%)	Water in Storage (ac-ft)
Alluvium and Valley Fill	6,470	--[2]	10[3]	30	19,400
Lower Arapahoe Formation	4,970	35[4]	15	30	22,400
Laramie-Fox Hills	6,350	200	120	30	228,600
TOTAL					270,400

1) Assumed value based upon data presented by Robson (1987).
2) Not estimated.
3) Estimated from the difference between alluvial and valley fill groundwater elevation (and bedrock elevation over RFP site).
4) Thickness of all Arapahoe sandstones and siltstones. Does not include claystone (which is assumed to have no significant water).

Modified From: EG&G Rocky Flats, Inc. (1991).

determination of the right to this ground water by the Water Court, whichever comes first, and the allowed average annual amount of withdrawal (Holland & Hart, Attorneys at Law, 1990).

The amount of recoverable non-tributary ground water in the Laramie-Fox Hills aquifer underlying the RFP can be calculated based upon the average saturated thickness of the aquifer (estimated to be about 120 ft), the specific yield (presumed by the Colorado State Engineer to be 15 percent), and the surface acreage overlying the non-tributary area (measured from maps to be about 6,350 ac). Therefore, the estimated recoverable non-tributary ground water in the Laramie-Fox Hills aquifer underlying the RFP is about 114,300 ac-ft. Annual non-tributary withdrawals may be made over a 100-year period at a rate of about 1,140 ac-ft/yr (about 700 gallons per minute (gpm)). This non-tributary ground water could be pumped to satisfy replacement or augmentation water required for implementation of a zero-discharge plan.

The potential for recovery of this non-tributary ground water is assessed later in this study. Only one well is known to be completed in the Laramie-Fox Hills aquifer at the RFP (Figure 2).

3.2.3 Arapahoe Formation

The upper Arapahoe Formation is eroded away at the RFP. The lower Arapahoe Formation is about 250 ft thick (Figures 1 and 3) in the central part of the RFP and consists mainly of claystones. However, it also contains at least six mappable sandstone intervals. These sandstone intervals vary in thickness from 0 ft to over 27 ft, and have vertical separations ranging from 2 ft to nearly 100 ft (Figure 1, Table 1). Because the sandstone intervals are fluvial (EG&G Rocky Flats, Inc., 1990), the sandstone channels are not present beneath all of the RFP. Generally, the Arapahoe sandstones that subcrop below the base of the alluvium, colluvium, and valley fill are oxidized and are pale orange, yellowish-gray, and dark yellowish-orange. The sandstones that are not in the weathered zone are light gray and olive gray. Most of the sandstones are very fine to medium grained (d_{50} = 0.06 millimeters (mm) to 0.09 mm), moderately sorted, and subangular to subrounded, silty, clayey, and quartzitic, with trough and planar cross-stratification. The

claystones and silty claystones in the Arapahoe Formation are light to medium olive-gray and occasionally olive-black with some dark yellowish-orange claystones in the weathered intervals near the base of the alluvium.

The Colorado State Engineer (VanSlyke and others, 1988c) has estimated the limits of the lower Arapahoe Formation in the vicinity of the RFP. The predominant water-yielding strata of the lower Arapahoe Formation are the saturated sandstones and siltstones. The clay-shale interbed units are generally assumed to have little water-yielding capabilities, even though large amounts of water may be stored within them. The Colorado State Engineer's maps do not include the clay-shale units as part of the saturated thickness of the Arapahoe Formation in the Denver basin. Figure 2 shows the approximate location of the base of the lower Arapahoe Formation at the RFP based upon interpretation of the Colorado State Engineer's maps. The lower Arapahoe Formation has been determined by the Colorado State Engineer to be non-tributary to streams. To the east of the RFP is the upper Arapahoe Formation (VanSlyke and others, 1988c).

The estimated water in storage beneath the RFP in lower Arapahoe Formation was estimated by EG&G Rocky Flats, Inc. (1991). Table 2 shows the estimated quantity of water stored in the areal extent of the lower Arapahoe Formation beneath the RFP plant boundary as shown on Figure 2. The average saturated thickness of the lower Arapahoe Formation was estimated from three on-site wells which penetrate the Arapahoe Formation (Figure 2). These wells indicate that only the basal sandstone of the lower Arapahoe Formation is saturated and has a thickness ranging from 0 to 30 ft. A saturated thickness of 15 ft was used for this study. The porosity of 30 percent was also assumed. The areal extent of 4,970 ac of Arapahoe Formation was measured from Figure 8 based upon aquifer limits taken from VanSlyke and others (1988c). The estimated water in storage in the lower Arapahoe Formation beneath the RFP is about 22,400 ac-ft.

According to the Colorado State Engineer (VanSlyke and others, 1988c), the water in the lower Arapahoe Formation beneath the RFP is non-tributary. The amount of non-tributary Arapahoe Formation water underlying the RFP can be calculated based upon the average saturated thickness

of the aquifer (estimated to be about 15 ft), the specific yield (presumed by the Colorado State Engineer to be 17 percent), and the surface acreage overlying the non-tributary area (measured from maps to be about 4,970 ac). Therefore, the estimated non-tributary water in the Arapahoe Formation aquifer underlying the RFP is about 12,700 ac-ft. Annual non-tributary withdrawals of water may be made over a 100-year period at a rate of about 127 ac-ft/yr (about 80 gpm). This non-tributary ground water could be used to satisfy replacement or augmentation water for the zero-discharge plan. The potential recovery of this non-tributary ground water is assessed later in this study.

3.3 HYDRAULIC CHARACTERISTICS OF THE BEDROCK AQUIFERS

Development of the non-tributary ground water beneath the RFP would most likely entail pumpage of the water using a wellfield located somewhere on the RFP. For purposes of this preliminary study, it was assumed that the wellfield would be in within the RFP and nearer the eastern boundary (Indiana Street) which is furthest away from the western limit of the Arapahoe and Laramie-Fox Hills aquifers, although a typical wellfield could be located nearly anywhere as long as the drawdown from the wellfield does not extend significantly outside the RFP boundary. Because the Arapahoe Formation saturated thickness beneath the RFP averages only about 15 ft, it was not included as part of the non-tributary water available for replacement or augmentation water. To assess the economic impacts of pumping the wellfield, several assumptions regarding the depth and spacing of wells and the hydraulic characteristics of the Laramie-Fox Hills aquifer beneath the RFP were made. The sensitivity of the assumptions are discussed in the following sections.

3.3.1 General Hydraulic Characteristics of the Laramie-Fox Hills Aquifer

The costs of obtaining water from the Laramie-Fox Hills aquifer underlying the RFP are sensitive to pumping lift, which is a function of annual water withdrawals as well as the estimated aquifer hydraulic properties. To estimate pumping lift, a preliminary analysis of expected maximum

wellfield drawdowns for various values of annual withdrawals, aquifer transmissivity, well spacing and individual well pumping rates was conducted.

Only one on-site well is known to be completed in the Laramie-Fox Hills aquifer. This well is located in the northwest corner of the RFP (Figure 2) and served as a water supply for the Wind Site. Several wells have been completed in the Laramie-Fox Hills aquifer north and south of the RFP. Many of these wells are near the western limit of the aquifer where ground-water conditions may be representative of those at the RFP (ASI, 1991a).

No hydraulic characteristics could be found for individual wells which are completed in the Laramie-Fox Hills aquifer east of the RFP. Because no information related to on-site or near-site Laramie-Fox Hills hydraulic characteristics could be located, values presented in the literature of the Denver basin were reviewed to assess potential Laramie-Fox Hills aquifer hydraulic characteristics such as aquifer depth, thickness, potentiometric surface elevation, transmissivity and storativity as well as indicator water-quality characteristics. Schneider (1980), Robson and others (1981), and Robson (1983, 1984, and 1987) describe aquifer characteristics of the Laramie-Fox Hills aquifer including values at the RFP based upon extrapolation and interpolation from values outside the RFP. These extrapolated and interpolated hydraulic characteristics were used in this study.

According to Schneider (1980), the aggregate sand and aquifer thickness of the Laramie-Fox Hills aquifer ranges from 42 to 360 ft and averages about 229 ft throughout the Denver basin. Typical well yields, based upon data from 93 wells, ranges from 1 to 90 gpm and averages about 22 gpm. At the RFP, Schneider (1980) shows the approximate sand thickness of the Laramie-Fox Hills aquifer varying from about 50 ft west of the Controlled Area to about 250 ft near State Route 128 and Indiana Street in the northeast corner of the RFP. The Laramie-Fox Hills aquifer thickness increases in an easterly direction from its outcrop in the West Buffer Zone of the RFP. Based upon Schneider's range of thickness contours at the RFP, it is estimated that the average sand thickness of the Laramie-Fox Hills aquifer at the RFP is about 120 ft. Robson and others

(1981) estimated that the thickness of the sandstone and siltstone units in the Laramie-Fox Hills aquifer at the RFP was about 100 ft. Estimates reported by EG&G Rocky Flats, Inc. (1991) indicate that the thickness of the Laramie-Fox Hills aquifer beneath the RFP averages about 120 ft.

Schneider (1980) estimated the elevation of the potentiometric surface of the Laramie-Fox Hills aquifer at the RFP. His estimates ranged from 6,100 ft above mean sea level (msl) near the outcrop in the West Buffer Zone, to about 5,500 ft msl near the intersection of State Route 128 and Indiana Street in the northeast corner of the RFP. These potentiometric surface elevations were based upon 1974 through 1978 data and included the Wind Site well located in the northwest corner of the RFP. The slope of the potentiometric surface, based upon Schneider's (1980) data, is toward the east-northeast at about 0.04 ft/ft. Robson and others (1981) also provided potentiometric surface contours at the RFP for the Laramie-Fox Hills aquifer. Their potentiometric elevations range from about 5,800 ft msl near the outcrop in the West Buffer Zone to about 5,300 ft msl near State Route 128 and Indiana Street, based upon water level measurements taken in 1978 only. They also present potentiometric contours for 1958 water-level measurements. The potentiometric surface elevations in 1958 ranged from about 5,800 ft msl near the outcrop to about 5,350 ft msl at Indiana Street.

Based upon data presented on both Schneider (1980) and Robson and others (1981), the depth to the top of the Laramie-Fox Hills aquifer at the RFP varies from about 700 ft in the west Buffer Zone at about the axis of the fold of the aquifer unit (see Figure 3), to over 1000 ft near Indiana Street. These depths range from about elevation 5,100 ft msl in the West Buffer Zone to about 4,600 ft msl near Indiana Street. Coupling these elevations with those of the potentiometric surface, indicates that potentiometric heads at the top of the Laramie-Fox Hills aquifer at the RFP may be about 700 ft except near the outcrop. At the outcrop the Laramie-Fox Hills is generally unconfined, which means that the potentiometric surface would not rise above the top of the aquifer if a piezometer fully penetrated the aquifer. Robson (1983) indicated that the RFP may have areas of the Laramie-Fox Hills which have temporarily unconfined conditions

during parts of the year or during dry years when recharge is low.

Robson (1983,1987) has published values of hydraulic conductivity, transmissivity and storativity of the Laramie-Fox Hills aquifer in the vicinity of the RFP. Pumping tests in the Laramie-Fox Hills aquifer north and south of the RFP have been analyzed by others and indicates that a typical hydraulic conductivity of the Laramie-Fox Hills aquifer at the RFP would average about 0.05 feet per day (ft/d). The range of hydraulic conductivities for nearby pumping tests and laboratory test from core samples was from 0.003 ft/d, south of the RFP (near the outcrop), to 1.0 ft/d, north of the RFP (near Marshall). Transmissivity may be estimated by multiplying the hydraulic conductivity times the aquifer thickness. For the RFP, the average saturated thickness is about 120 ft. Assuming a hydraulic conductivity of 0.05 ft/d, gives a transmissivity of 6 square feet per day (ft^2/d). Robson (1983) estimates that the transmissivity of the Laramie-Fox Hills aquifer in the vicinity of the RFP is about 5 ft^2/d. For purposes of this study, it has been assumed that the transmissivity of the Laramie-Fox Hills aquifer is about 6 ft^2/d or about 50 gallons per day per ft (gpd/ft).

Storativity estimates of the Laramie-Fox Hills aquifer at the RFP also have been made by Robson (1983, 1987). The confined storativity of the Laramie-Fox Hills was estimated by Robson to be about 2×10^{-4}. The unconfined storativity or specific yield has been variously estimated by Robson and others (1981) and Robson (1983 and 1987) to vary from a less than 10 percent to over 30 percent for various locations in the Laramie-Fox Hills aquifer. The Colorado State Engineer presumes that the specific yield of the Laramie-Fox Hills, for purposes of administering non-tributary ground water, is 15 percent.

Water quality of the Laramie-Fox Hills aquifer at the RFP may range from good to poor compared to EPA Primary and Secondary Drinking-Water Standards (EPA, 1989). Robson (1987) estimates the water quality of the Laramie-Fox Hills at the RFP by extrapolating and interpolating from both on-site (1 well) and off-site data. The water in the Laramie-Fox Hills aquifer is generally a sodium-bicarbonate type. The Laramie-Fox Hills aquifer is overlain by the

shaly upper part of the Laramie Formation (Figure 1). When the direction of ground-water movement is considered, poor quality water in areas of the aquifer seems to occur as a result of soluble minerals being carried into the aquifer from surface sources or from sources within the upper part of the Laramie Formation. This is especially true in the western areas of the RFP where the shaly upper part of the Laramie Formation is beyond the edge of the overlying Arapahoe aquifer (Figure 2). Dissolved solids concentrations in the Laramie-Fox Hills aquifer water are about 300 milligrams per liter (mg/L) at the RFP (Robson and others, 1981). Dissolved sulfate concentrations vary from 25 mg/L to 250 mg/L at the RFP. Some areas of the Laramie-Fox Hills aquifer, north and south of the RFP and beyond the edge of the overlying Arapahoe aquifer, have dissolved sulfate concentrations higher than 250 mg/L, which is the EPA primary drinking-water standard (EPA, 1989). High dissolved iron concentrations also are common in the Laramie-Fox Hills aquifer water and generally range from 20 mg/L to 200 mg/L (Robson and others (1981). The EPA drinking-water standard for iron is 300 mg/L. Wells drilled in the Laramie-Fox Hills aquifer have been known to produce methane gas from the coal seams which are present in the Laramie Formation.

3.3.2 Wellfield Operations in the Laramie-Fox Hills Aquifer

In order to assess the feasibility of withdrawing water from the Laramie-Fox Hills aquifer to use as potential replacement or augmentation water for zero discharge alternatives, an analysis of a hypothetical wellfield at the RFP was undertaken. Drawdowns in individual wells in the wellfield and at selected locations between wells were calculated using the Theis equation and superposition (Theis, 1935). Based upon the hydraulic characteristics of the Laramie-Fox Hills aquifer presented in Section 3.3.1, drawdowns were calculated assuming that the aquifer was of infinite areal extent, had an initial potentiometric surface 700 ft above the top of the aquifer (confined). Drawdowns in excess of 700 ft would indicate that withdrawal of water at the indicated pumping rate or well spacing was not feasible. The transmissivity was assumed to be 50 gpd/ft, and the storativity was assumed to be 2×10^{-4}.

Figure 4 indicates the number of pumping wells in a typical wellfield required to provide annual water withdrawals from the Laramie-Fox Hills Aquifer ranging from zero to 500 ac-ft/yr, and for individual wells pumping 10, 20 and 30 gpm. For a typical annual withdrawal of 120 ac-ft/yr, about 12 wells pumping 10 gpm would be needed. If the annual withdrawal were 480 ac-ft/yr, then about 48 wells pumping 10 gpm would be needed.

Drawdowns were estimated in typical wellfields (Figures 5, 6, and 7) for wells having pumping rates of 10 gpm for an assumed transmissivity of 50 gpd/ft and for equally-spaced wells of 2000 ft (Figure 5), 3000 ft (Figure 6), and 4000 ft (Figure 7). The drawdowns assume continuous pumping for a period of ten years. It was judged reasonable that if the project life was 30 years, then maximum drawdowns at the 10-year time period would be representative of average, steady state, wellfield drawdowns over an assumed 30-year lifetime of the project.

Maximum drawdowns for the Laramie-Fox Hills Aquifer beneath the RFP for selected well spacings and annual withdrawals are shown on Figure 8. Maximum drawdowns for the transmissivity and various well spacings often exceeded the 700 ft of available drawdown depending upon the annual withdrawals (number of wells) and the spacing of wells. For an assumed transmissivity of 50 gpd/ft and a well spacing of 2000 ft, about 36 ac-ft/yr could be withdrawn from the system without exceeding the 700-ft drawdown limit (Figure 8). When the well spacing was increased from 2000 ft to 3000 ft with aquifer characteristics as previously assumed, maximum annual withdrawals increased to about 41 ac-ft/yr (Figure 8). At a well spacing of 4000 ft, maximum annual withdrawals were estimated to be about 46 ac-ft/yr (Figure 8). These withdrawals are not very sensitive to well spacing because of the assumption that the Laramie-Fox Hills is confined. Also, the maximum annual withdrawal of only between 40 and 50 ac-ft/yr will not offset the minimum estimated annual replacement or augmentation water demand of 120 ac-ft/yr needed under zero discharge. Therefore, an additional source of augmentation or replacement water would be needed. A general rule for the withdrawal of water from the Laramie-Fox Hills Aquifer beneath the RFP is that many wells having small individual pumping rates would be needed to recover the non-tributary ground water in the aquifer.

The assumption that the Laramie-Fox Hills Aquifer beneath the RFP is infinite in areal extent tends to produce a best-case scenario in terms of pumping lift. Physically, it is realistic that the Laramie-Fox Hills Aquifer is bounded on the west, and therefore expected pumping lifts may be slightly greater or withdrawals slightly lower than those predicted by the assumption of infinite area extent. Because there are little or no data on aquifer hydraulic characteristics of the Laramie-Fox Hills Aquifer at the RFP, it was judged that a more complete analysis using boundary conditions on the aquifer was not warranted in this study.

For the economic analysis performed in Section 4.0, drawdowns calculated at the end of 10 years of continuous pumping for a wellfield having a 4000-ft spacing, well pumping rates of 10 gpm, and a transmissivity of 50 gpd/ft were used. The maximum drawdowns for these assumptions for various annual withdrawals ranging from 10 ac-ft/yr to 50 ac-ft/yr are relatively sensitive and range from about 600 to 1000 ft below ground surface. The economic analyses also assumed that pumping would be year-round. The above assumptions generally conform to a reasonable but quite severe case involving water withdrawals from the Laramie-Fox Hills Aquifer system underlying the RFP.

4.0 FINANCIAL ANALYSES

4.1 PROJECT COSTS

The cost analyses presented in this section examine the costs of pumping water from the Laramie-Fox Hills Aquifer wellfield at the RFP without delivering the water to any specific location on the RFP. Two possible delivery points, however, may be Walnut Creek or Woman Creek to replace or augment surface water or ground water diverted out of priority as required by implementation of a zero-discharge plan. The average annual withdrawals from the Laramie-Fox Hills Aquifer system were assumed to range from 10 ac-ft/yr to 50 ac-ft/yr. On-site costs were estimated for project construction, including the cost of wells, pumps and interwell pipe. Also included were interest costs during construction, start-up costs, working capital, and owner's general expense. Annual operation and maintenance costs including labor, supplies and materials, along with electric power costs were estimated. These costs were annualized with the total annual costs including annual operation and maintenance (O&M), annual depreciation and non-depreciation capital costs. Unit annual costs were obtained by dividing the total annual cost (in dollars) by the annual water withdrawal (in ac-ft). These unit annual costs ($/ac-ft) formed the basis for comparison of different on-site alternatives as well as lease of off-site water for replacement or augmentation. The cost estimates were made using an in-house computer program, COST, as described in Appendix A. This computer program has been used to estimate the costs of ground-water withdrawals from deep aquifers in the San Luis Valley, Colorado for the Colorado Water Resources and Power Development Authority (In-Situ, Inc., 1986).

Certain cost factors were assumed to be constant for each case. These constant cost factors include the following assumed values: $0.075/kilowatt-hour (kWh) for electricity, 70 percent pumping efficiency, pipe-friction coefficient of 135, annual interest rate of 7 percent, and annual insurance rate of 0.25 percent. The unit electricity cost was judged to be representative of electricity either purchased at the RFP or generated on-site. The assumed pumping-efficiency level incorporates a number of physical and time-dependent factors and is judged to represent a

realistic average value. The pipe-friction coefficient was based upon professional engineering judgement. The cost-based factors were judged to represent reasonable average values. The 7 percent interest rate represents a non-inflationary rate judged as depicting the average cost of obtaining capital for water-development projects by governmental agencies. Annualized costs were amortized over an assumed 30-year project life. Figure 9 shows the results of the water-development cost estimates in terms of unit annual water costs in both $/ac-ft and $ per thousands gallons versus annual withdrawals from the Laramie-Fox Hills Aquifer beneath the RFP.

The cases used to estimate costs consisted between 3 and 8 wells (including standby wells), 1120 ft deep, pumping 10 gpm; a transmissivity of 50 gpd/ft; a storativity of 2×10^{-4}; and a 4000-ft well spacing. Annual costs of water for annual withdrawals ranging from 10 to 50 ac-ft/yr varied from $1,325/ac-ft to $2,600/ac-ft to bring water from the Laramie-Fox Hills aquifer and transport it 1 mile to a point of use. The variation in annual unit costs versus quantity of water withdrawn are shown on Figure 9.

Lease of water for augmentation or replacement from Coors with discharge into Clear Creek or the South Platte River to meet South Platte River calls would have an annual cost of about $300/ac-ft (Neil Jaquet, personal communication). It is judged that this unit rate for leased augmentation or replacement water is typical of costs in the Denver metropolitan area. Some of the uncertainties with lease water is that it is generally not guaranteed to be available when needed. In the case of Coors, lease water for augmentation or replacement would be for a 5-year maximum period with no guarantee of renewal (Neil Jaquet, personal communication). The annual cost of 10 ac-ft/yr of water leased from Coors would be about $3000. The full quantity of between 120 ac-ft and 480 ac-ft of augmentation or replacement water required for a zero-discharge plan would cost between $36,000 and $144,000 annually.

Based upon the analysis of non-tributary ground-water at the RFP, it would be less expensive to lease water for replacement or augmentation of downstream water diverted out of priority under

zero discharge than to develop on-site Laramie-Fox Hills aquifer water. However some effort should be made to investigate on-site non-tributary ground water as an alternative to partial fulfillment of augmentation or replacement water at the RFP. Other leased water should also be investigated after the quantity of augmentation or replacement water is better identified. Redundant leases may be needed to help provide augmentation water during dry years.

5.0 SUMMARY AND CONCLUSIONS

This non-tributary ground-water study assessed the physical and economic feasibility of pumping non-tributary ground water from beneath the RFP to replace stored or diverted surface water and tributary ground water, for use as makeup/dilution water, or augmentation/substitute supply water for injured water rights. Ground water underlying the RFP in the Arapahoe and Laramie-Fox Hills aquifers is considered to be the property of the overlying land owner, unless consent has been given by the landowner, either express or implied, to the withdrawal of the water from that aquifer by another.

Augmentation or replacement water will most likely be needed to replace STP effluent that would be recycled (up to 237 ac-ft annually). Water would also be needed to augment surface-water runoff detained on site (between 110 and 233 ac-ft annually), as well as tributary ground water diverted out of priority (about 10 ac-ft annually). Depending upon the selected zero-discharge alternative, between 120 and 480 ac-ft of augmentation or replacement water could be needed to offset stream depletions.

In order to assess the feasibility of withdrawing water from the Laramie-Fox Hills aquifer to use as potential replacement or augmentation water for zero discharge alternatives, an analysis of a hypothetical wellfield at the RFP was undertaken. Drawdowns in individual wells in the wellfield and at selected locations between wells were calculated using the Theis equation and superposition. Based upon hydraulic characteristics of the Laramie-Fox Hills aquifer, drawdowns were calculated assuming that the aquifer was of infinite areal extent, had an initial potentiometric surface 700 ft above the top of the aquifer (confined). Drawdowns in excess of 700 ft would indicate that withdrawal of water at the indicated pumping rate or well spacing was not feasible.

Results of the drawdown analysis indicated that between 40 and 50 ac-ft annually could be withdrawn from non-tributary ground water underlying the RFP. This quantity is not enough to

offset the estimated 120 ac-ft to 480 ac-ft of augmentation or replacement water needed under zero-discharge alternatives. Therefore, another source of augmentation or replacement water is needed. This other source could be lease water from an existing Denver basin water user who has excess water and would be willing to provide it to the RFP. There is generally no guarantee that the lease water would be available when needed and the leases are usually of short duration (2 to 5 years).

The cases used to estimate non-tributary water withdrawal costs consisted of between 3 and 8 wells, 1120-ft deep, pumping 10 gpm; a transmissivity of 50 gpd/ft; a storativity of 2×10^{-4}; and a 4000-ft well spacing. Annual costs of non-tributary water for annual withdrawals ranging from 10 to 50 ac-ft/yr varied from $1,325/ac-ft to $2,600/ac-ft to bring water from the Laramie-Fox Hills aquifer and transport it 1 mile to a point of use. Lease of water from Coors with discharge into Clear Creek or the South Platte River to meet South Platte River calls would have an annual cost of about $300/ac-ft. Based upon the analysis of non-tributary ground-water at the RFP, it would be less expensive to lease water for replacement or augmentation of downstream water diverted out of priority under zero discharge than to develop on-site Laramie-Fox Hills aquifer water.

6.0 ACKNOWLEDGMENTS

This study was conducted under the general supervision of Mr. Michael G. Waltermire, P.E., Project Manager, Advanced Sciences, Inc. Work involving this project task was under the technical direction of Dr. James R. Kunkel, P.E., ASI Principal Scientist. This study report was written by Dr. Kunkel, with assistance from Nick Massaro, ASI Draftsmen. The report was reviewed by Mr. Michael J. Rengel, P.E., ASI Project Director, Dr. Timothy D. Steele, P.H., Physical Sciences Group Manager, and Mr. Waltermire. EG&G responsive reviewers of this report included:

R. A. Applehans, PE/CE-ER

This report was prepared and submitted in partial fulfillment of the Zero-Offsite Water-Discharge Study being conducted by ASI on behalf of EG&G Rocky Flats, Inc. EG&G's Project Engineer for the Study was Mr. R. A. Applehans of EG&G's Plant Engineering/-Civil Engineering-Environmental Restoration (PE/CE-ER) division.

7.0 REFERENCES

Advanced Sciences, Inc. (ASI), 1990a, Predecisional Draft, Zero-Offsite Water-Discharge Study Scope Evaluation: Prepared for EG&G Rocky Flats, Inc., Project No. 667, Task 16, March 30, 34 p., 2 appendices, and 1 plate.

Advanced Sciences, Inc. (ASI), 1990b, EG&G Rocky Flats, Inc., Request for Proposal BA79844GS, Non-Tributary Ground-water Study, EG&G Job No. 401009: Prepared for Facilities Engineering, Plant Civil-Structural Engineering, August 3, 5 p.

Advanced Sciences, Inc. (ASI), 1990c. Project Management Plan, Surface-Water and Ground-Water Rights Study, Task 14 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G rocky Flats, Inc., August 29, 6 p.

Advanced Sciences, Inc. (ASI), 1991a, Surface-Water and Ground-Water Rights Study, Task 14 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc., Project No. 208.0114, May 21, 59 p., 18 tables, 8 figures, 1 plate, and 1 appendix.

Advanced Sciences, Inc. (ASI), 1991b, Draft Feasibility of Ground-Water Diversion/Cutoff Study, Task 26 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc., Project No. 208.0126, April 30, 17 p., 3 tables, 6 figures, 1 appendix.

Advanced Sciences, Inc. (ASI), 1991c, Project Management Plan, Augmentation Plan for the Rocky Flats Plant, Task 28 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc., January 17, 5 p., 2 appendices.

Advanced Sciences, Inc. (ASI), 1991d, Project Management Plan, Consolidation and Zero-Discharge Plan, Task 30 of the Zero-Offsite Water-Discharge Study: Prepared for EG&G Rocky Flats, Inc., January 17, 5 p., 2 appendices.

Colorado Revised Statutes, 1973, Section 37-80, and 37-92, et. seq. (Supplement 1989).

Denver Board of Water Commissioners (Denver Water Department), 1978, Letter from G. E. Bishop, Water Resource Engineer, Denver Water Department to D. C. Hunt, Manager, Environmental Sciences Department, Rockwell International, Rocky Flats Plant, November 20, 2 p. with attachment.

EG&G Rocky Flats, Inc., 1990, Draft Geologic Characterization Report: Prepared by Advanced Sciences, Inc. for EG&G Rocky Flats, Inc., January 3.

EG&G Rocky Flats, Inc., 1991, Groundwater Protection and Monitoring Program Plan: Prepared by Advanced Sciences, Inc. for EG&G Rocky Flats, Inc., April 15.

Holland & Hart, Attorneys at Law, 1990, Report on the Water Rights, Water Quality and Environmental Issues Presented by the Zero Discharge Study for the Rocky Flats Plant: Prepared for EG&G, March 5, 92 p.

Holme, Roberts and Owen, Attorneys at Law, 1990, Letter to Wright Water Engineers, Inc., September 27: Appendix C - Water Rights Evaluation from Holme, Roberts and Owen, Rocky Flats Surface Water Management Plan, DOE, 1991.

In-Situ, Inc., 1986, San Luis Valley Confined Aquifer Study (Phase I), Interim Task 1 Report, Water Demands/Economic Analyses: Prepared for Colorado Water Resources and Power Development Authority, Prepared in cooperation with Robert A. Young, HRS Consultants, Inc., John C. Halepaska & Associates, Inc., and Robert E. Moran, Project No. 4332, August 19, 24 p., 8 tables, 5 figures, 4 appendices.

Robson, S. G., 1983, Hydraulic Characteristics of the Principal Bedrock Aquifers in the Denver Basin, Colorado: U. S. Geological Survey Hydrologic Investigations Atlas HA-659, Prepared in Cooperation with the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer; the Denver Board of Water Commissioners; and Adams and Arapahoe Counties, 3 sheets, 1:500,000.

Robson, S. G., 1984, Bedrock Aquifers of the Denver Basin, Colorado -- A Quantitative Water-Resources Appraisal: U. S. Geological Survey Open-File Report 84-431, Prepared in Cooperation with the Colorado Department of Natural Resources, Office of the State Engineer; the Denver Board of Water Commissioners; and Adams, Arapahoe, Douglas, Elbert and El Paso Counties, 111 p. (Superseded by Professional Paper 1257).

Robson, S. G., 1987, Bedrock Aquifers of the Denver Basin, Colorado -- A Quantitative Water-Resources Appraisal: U. S. Geological Survey Professional Paper 1257, Prepared in Cooperation with the Colorado Department of Natural Resources, Office of the State Engineer; the Denver Board of Water Commissioners; and Adams, Arapahoe, Douglas, Elbert and El Paso Counties, 73 p., 5 plates, (Supersedes Open-File Report 84-431).

Robson, S. G., A. Wacinski, S. Zawistowski and J. C. Romero, 1981, Geologic Structure, Hydrology, and Water Quality of the Laramie-Fox Hills Aquifer in the Denver Basin, Colorado: U. S. Geological Survey Hydrologic Investigations Atlas HA-650, Prepared in Cooperation with the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer; the Denver Board of Water Commissioners; and Adams, Arapahoe, Douglas, Elbert and El Paso Counties, 3 sheets, 1:500,000.

Rockwell International, 1978, Letter from D. C. Hunt, Manager, Environmental Studies, Rocky Flats Plant to J. L. Ogilvie, Denver Water Department, October 10, 1 p.

Schneider, P. A., Jr., 1980, Water-Supply Assessment of the Laramie-Fox Hills Aquifer in Parts of Adams, Boulder, Jefferson and Weld Counties, Colorado: U. S. Geological Survey Water-Resources Investigations Open-File Report 80-327, Prepared for the U. S. Bureau of Reclamation, Lakewood, CO., 17 p., 6 plates.

Spencer, F. D., 1961, Bedrock Geology of the Louisville Quadrangle, Colorado Bedrock Geology: U.S. Geological Survey Geological Quadrangle Map GQ-151, Lat. 39°52'30" to 40°, Long. 105°07'30" to 105°15', Scale 1:24,000, Contour Interval 10 Feet.

Theis, C. V., 1935, The Relation between the Lowing of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage: Transactions, American Geophysical Union, v. 16, pp. 519-524.

U.S. Department of Energy (DOE), 1991, Draft Rocky Flats Surface Water Management Plan: Prepared by EG&G Rocky Flats, Inc., Golden, Colorado, 2 Volumes, March.

U.S. Department of Energy (DOE) and State of Colorado, 1989, Agreement in Principle Between the United States Department of Energy and the State of Colorado: June 28, 25 p.

U. S. Department of Energy (DOE), 1979, Letter from A. P. Baker, Contracting Officer, Facilities & Construction Management Division, DOE Rocky Flats to G. E. Bishop, Water Resource Engineer, Denver Water Department, July 13, 1 p.

U. S. Environmental Protection Agency (EPA), 1989, Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water - A Compendium of Examples: Office of Emergency and Remedial Response, EPA/540/2-89/057, October, 144 p.

Van Horn, R., 1957, Bedrock Geologic Map of the Golden Quadrangle, Jefferson County, Colorado: USGS Geologic Quadrangle Map GQ-103, Lat. 39°45' to 39°52'30", Long. 105°07'30" to 105°15', Scale 1:24,000, Contour Interval 10 Feet.

Van Horn, R., 1972, Surficial and Bedrock Geologic Map of the Golden Quadrangle, Jefferson County, Colorado: Map I-761-A, Lat. 39°45' to 39°52'30", Long. 105°07'30" to 105°15', Scale 1:24,000, Contour Interval 10 Feet.

VanSlyke, G., J. Romero, G. Moravec, and A. Wacinski, 1988a, Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Dawson, Denver Basin, Colorado: Denver Basin Atlas No. 1, DBA-1, Colorado Division of Water Resources.

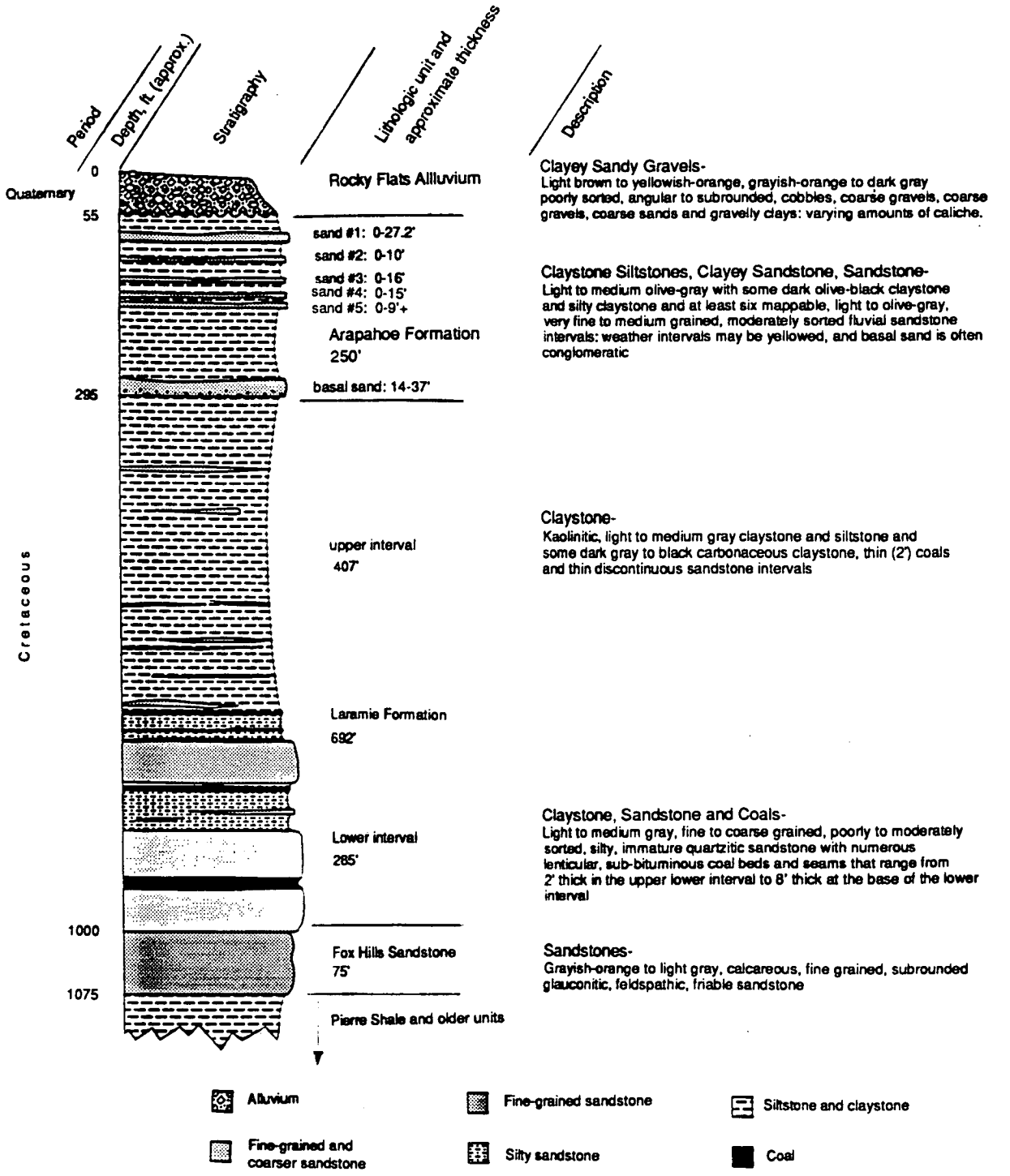
VanSlyke, G., J. Romero, G. Moravec, and A. Wacinski, 1988b, Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Denver Aquifer, Denver Basin, Colorado: Denver Basin Atlas No. 2, DBA-2, Colorado Division of Water Resources.

VanSlyke, G., J. Romero, G. Moravec, and A. Wacinski, 1988c, Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Arapahoe Aquifer, Denver Basin, Colorado: Denver Basin Atlas No. 3, DBA-3, Colorado Division of Water Resources.

VanSlyke, G., J. Romero, G. Moravec, and A. Wacinski, 1988d, Geologic Structure, Sandstone/Siltstone Isolith, and Location of Non-Tributary Ground Water for the Laramie-Fox Hills Aquifer, Denver Basin, Colorado: Denver Basin Atlas No. 4, DBA-4, Colorado Division of Water Resources.

Weimer, R. J., 1976, Cretaceous Stratigraphy, Tectonics, and Energy Resources, Western Denver Basin: In Studies of Colorado Field Geology, Colorado School of Mines Professional Contributions No. 8.

FIGURES



GENERALIZED STRATIGRAPHIC SECTION
ROCKY FLATS PLANT

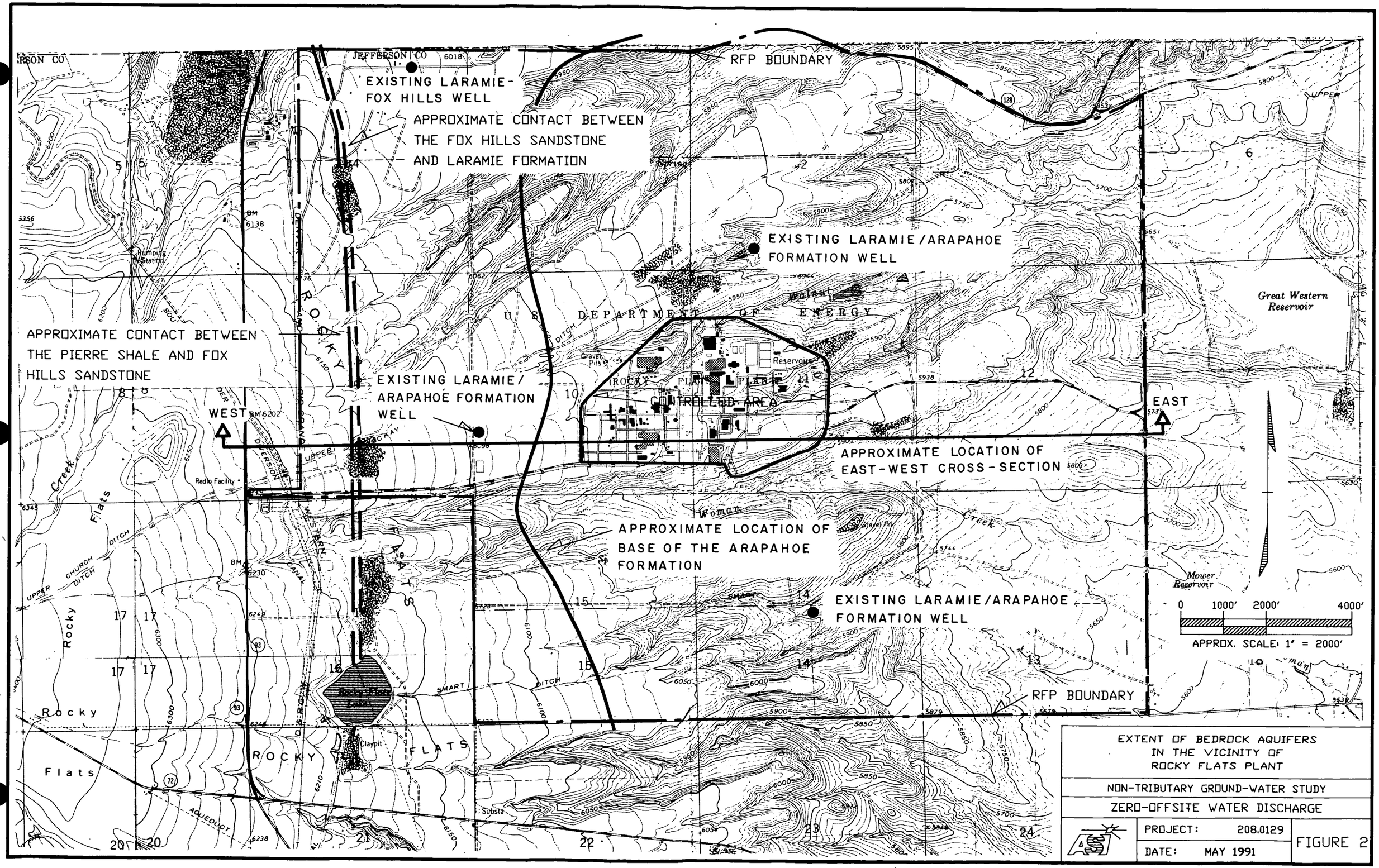
NON-TRIBUTARY GROUND-WATER STUDY

ZERO OFFSITE WATER DISCHARGE

PROJECT: 208.0129

DATE: MAY 1991

FIGURE 1



EXTENT OF BEDROCK AQUIFERS IN THE VICINITY OF ROCKY FLATS PLANT

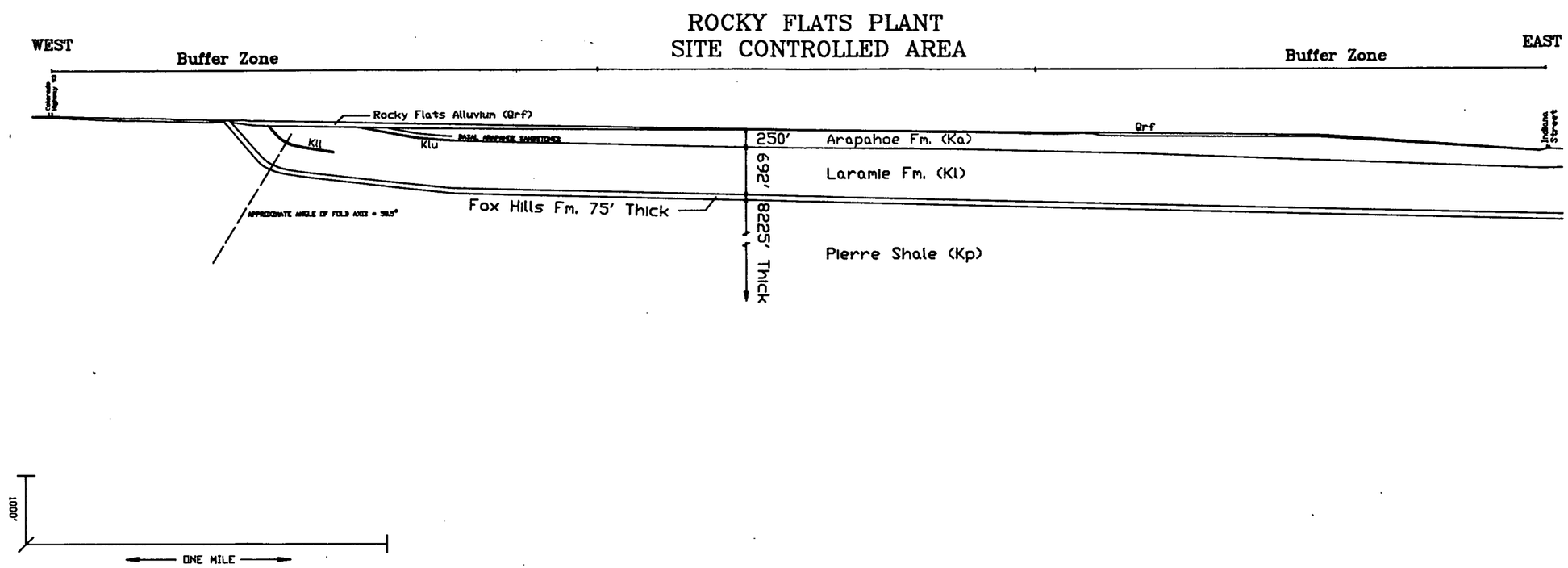
NON-TRIBUTARY GROUND-WATER STUDY

ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.0129

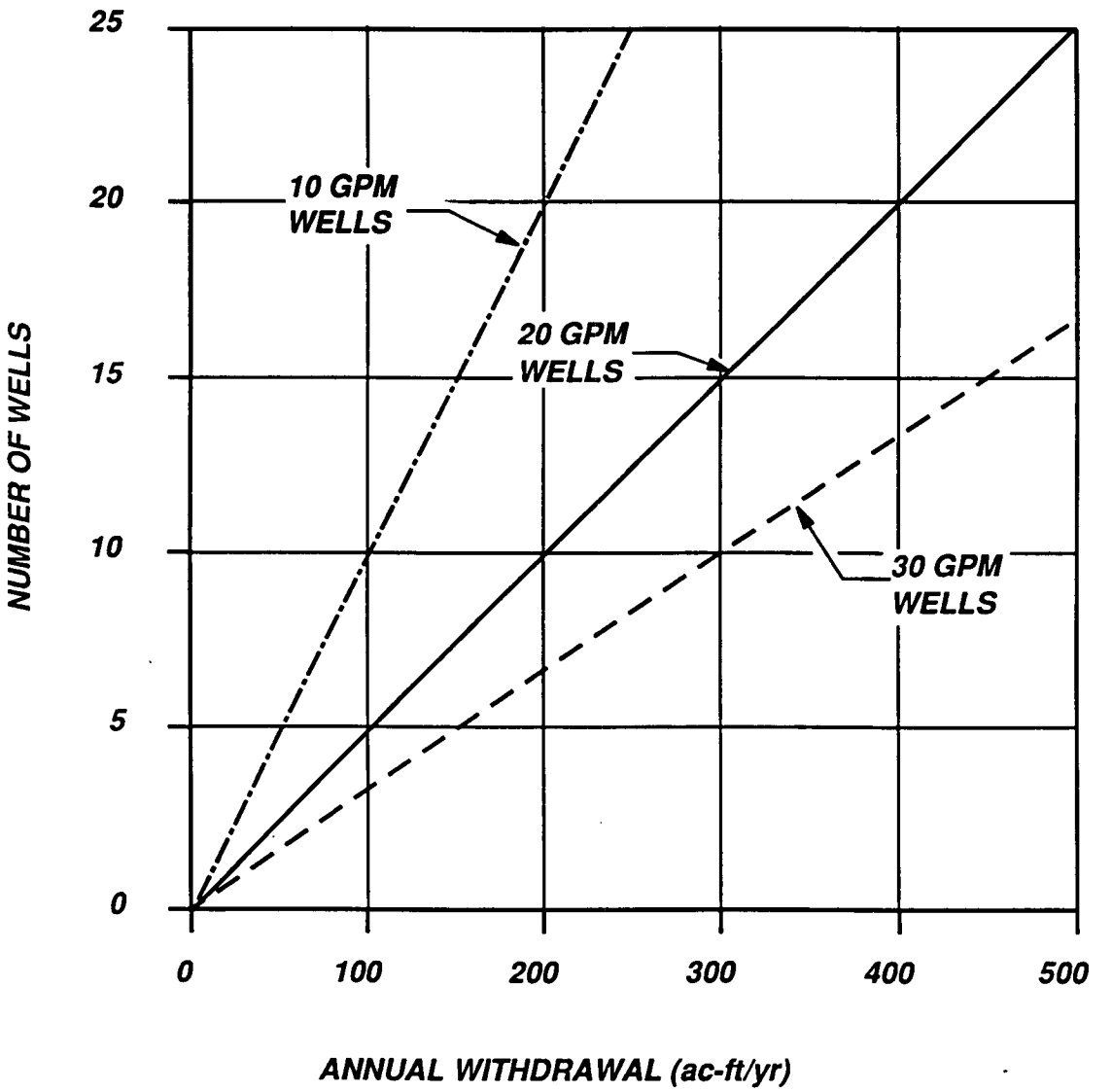
DATE: MAY 1991

FIGURE 2

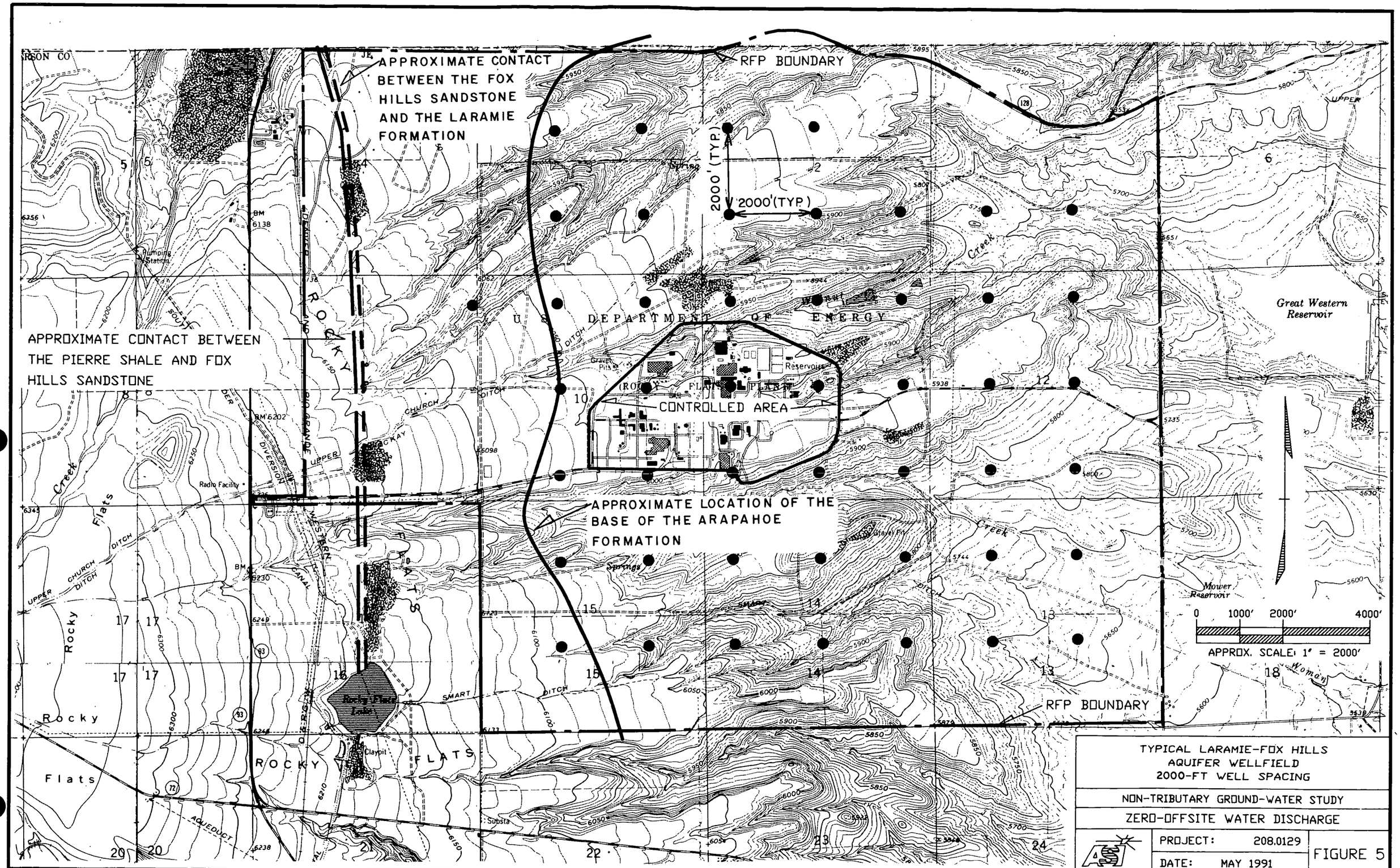


SOURCE: EG&G ROCKY FLATS, INC. (1990)

EAST-WEST GEOLOGIC CROSS-SECTION ROCKY FLATS PLANT		
NON-TRIBUTARY GROUND-WATER STUDY		
ZERO-OFFSITE WATER DISCHARGE		
	PROJECT: 208.0129	FIGURE 3
	DATE: MAY 1991	



NUMBER OF WELLS VERSUS ANNUAL		
NON-TRUBUTARY GROUND-WATER STUDY		
ZERO OFFSITE WATER DISCHARGE STUDY		
	PROJECT 208.0129	FIGURE 4
	DATE: MAY 1991	

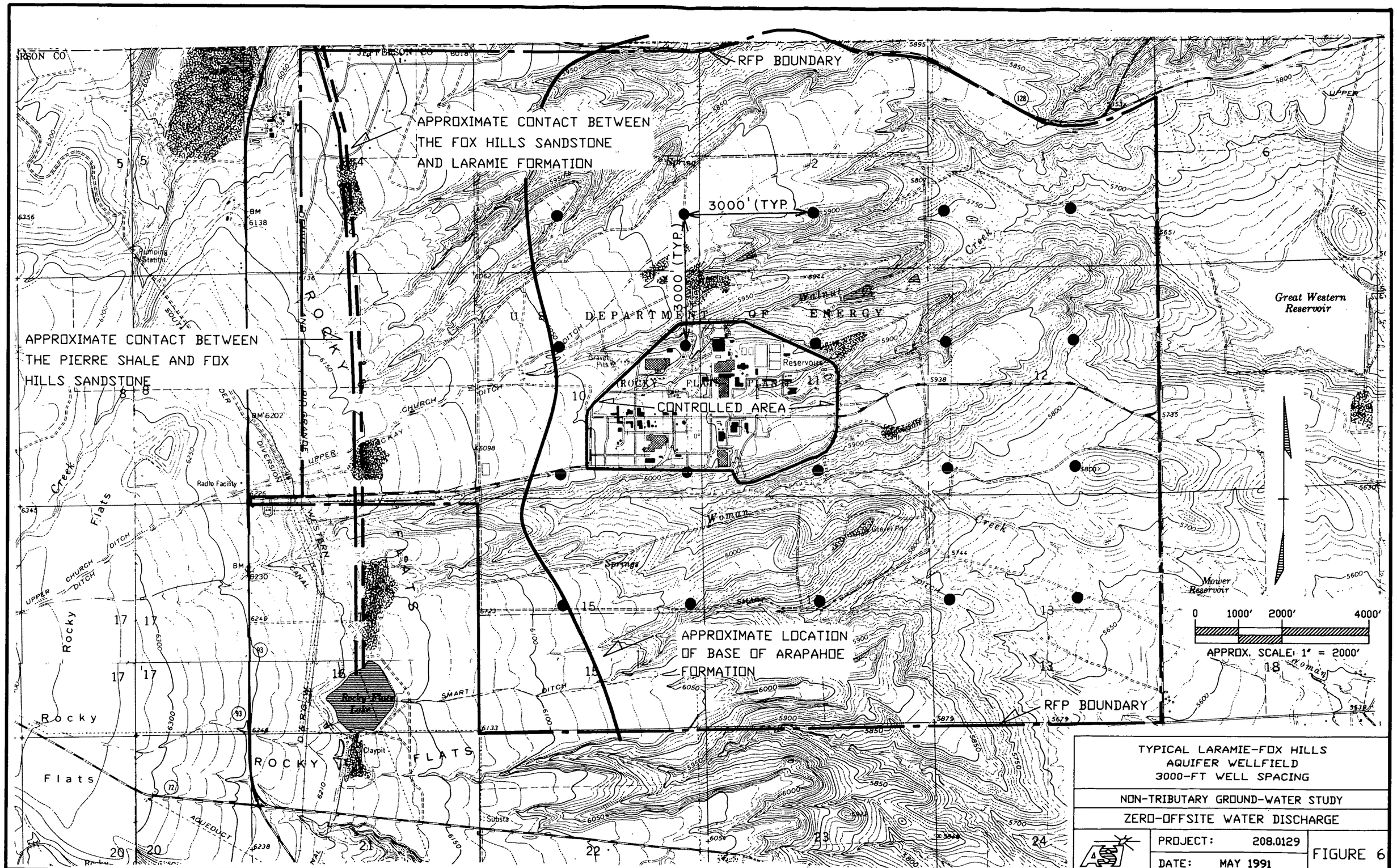


TYPICAL LARAMIE-FOX HILLS AQUIFER WELLFIELD 2000-FT WELL SPACING

NON-TRIBUTARY GROUND-WATER STUDY

ZERO-OFFSITE WATER DISCHARGE

PROJECT:	208.0129	FIGURE 5
DATE:	MAY 1991	



TYPICAL LARAMIE-FOX HILLS AQUIFER WELLFIELD 3000-FT WELL SPACING

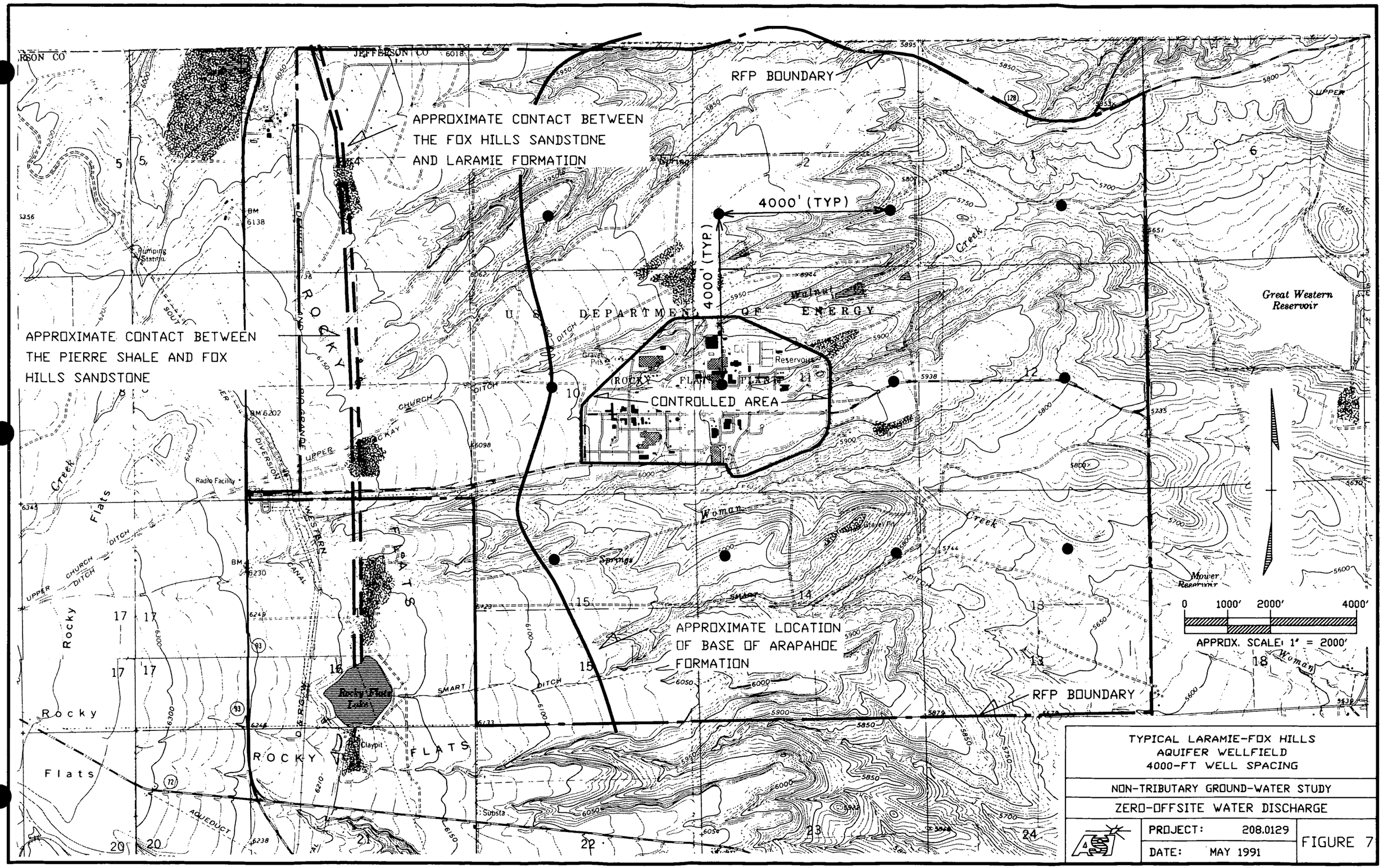
NON-TRIBUTARY GROUND-WATER STUDY

ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.0129

DATE: MAY 1991

FIGURE 6



TYPICAL LARAMIE-FOX HILLS AQUIFER WELLFIELD 4000-FT WELL SPACING

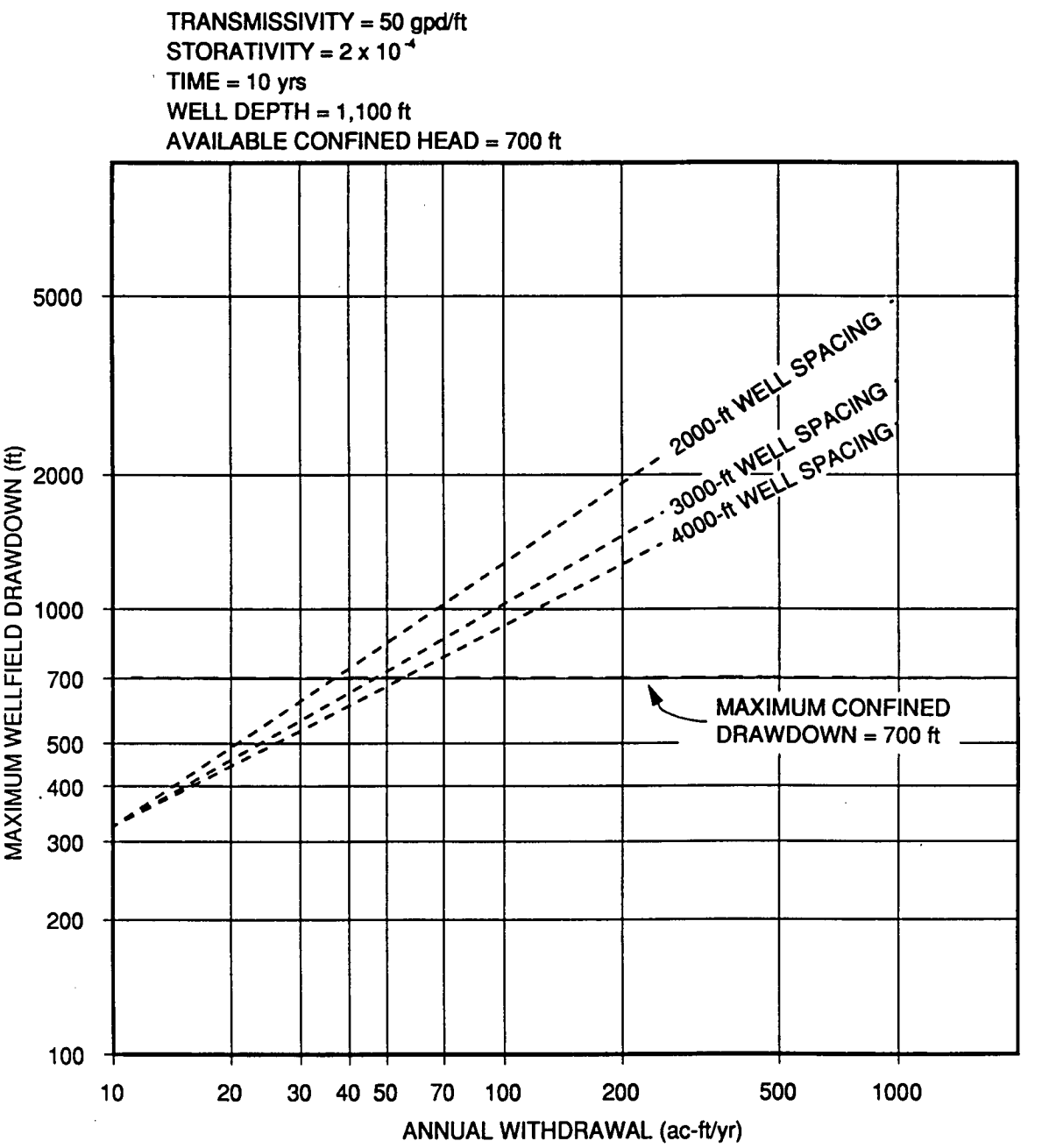
NON-TRIBUTARY GROUND-WATER STUDY

ZERO-OFFSITE WATER DISCHARGE

PROJECT: 208.0129

DATE: MAY 1991

FIGURE 7



MAXIMUM POTENTIOMETRIC SURFACE DECLINE FROM A RFP WELLFIELD FOR SELECTED ANNUAL WITHDRAWALS AND WELL SPACINGS

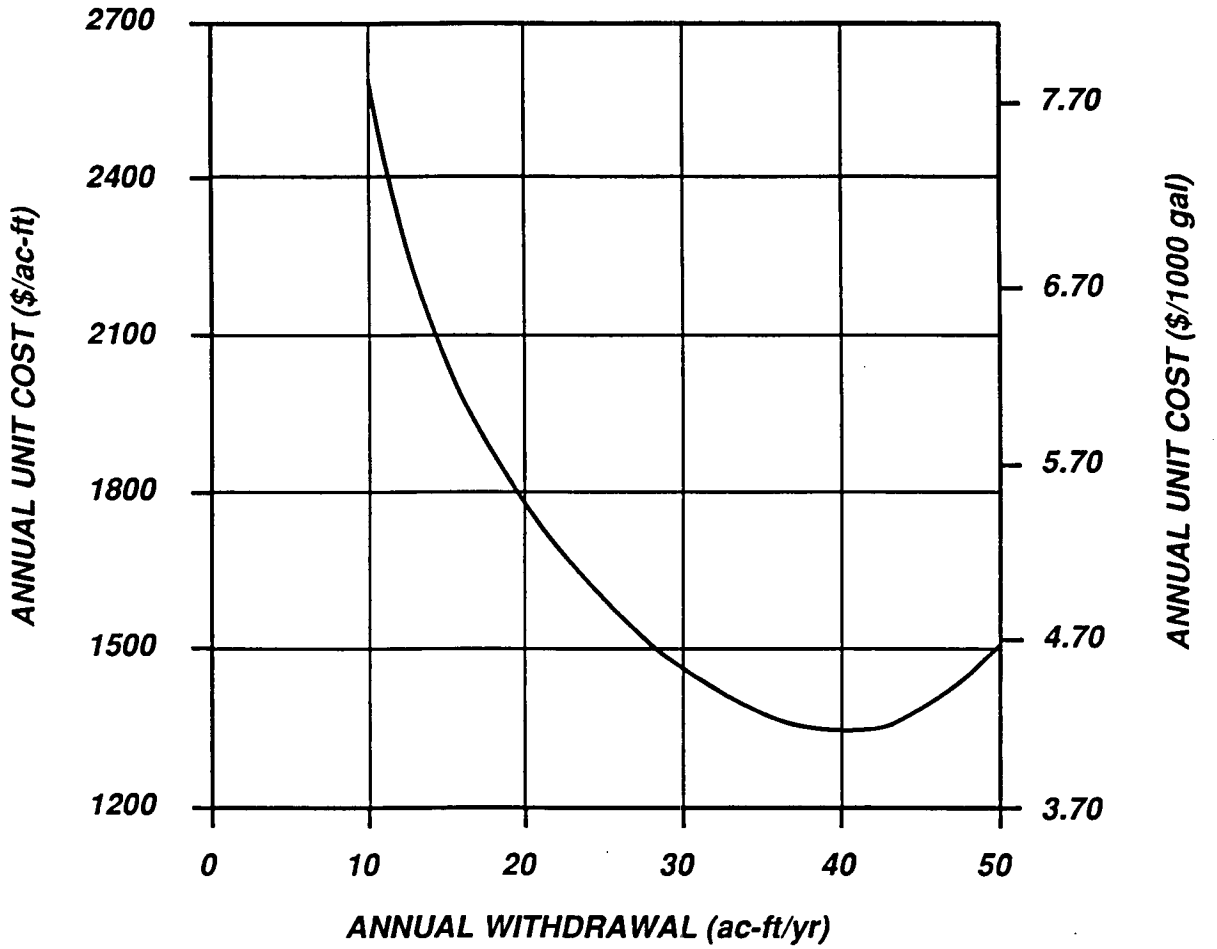
NON-TRUBUTARY GROUND-WATER STUDY

ZERO OFFSITE WATER DISCHARGE STUDY

PROJECT 208.0129

DATE: MAY 1991

FIGURE 8



ANNUAL UNIT COST OF LARAMIE-FOX HILLS AQUIFER WATER AT RFP		
NON-TRUBUTARY GROUND-WATER STUDY		
ZERO OFFSITE WATER DISCHARGE STUDY		
	PROJECT 208.0129	FIGURE 9
	DATE: MAY 1991	

A

APPENDIX A

DESCRIPTION OF CALCULATION FACTORS FOR THE COMPUTER PROGRAM "COST"

APPENDIX A
DESCRIPTION OF CALCULATION FACTORS FOR THE COMPUTER PROGRAM "COST"

The following appendix sections describe the calculations involved in the FORTRAN computer program COST and its subroutines. The program uses functional relationships to calculate facility sizes, quantities and costs. Not all of the features of the COST program were used in this particular application (such as terminal water storage facilities, booster stations, and open channels).

1.0 WELLS, PUMPS AND INTERWELL PIPE

1.1 NUMBER OF WELLS

The number of wells is equal to the peak flow rate divided by the yield per well rounded up, plus a standby capacity of 10 percent of the total number of wells. The standby capacity, however, cannot be less than one nor greater than 10 wells. The equation to calculate the number of wells is given by:

$$\text{NWA} = \text{peak flow rate/yield per well (rounded up)}$$

$$\text{Number of wells} = \text{NWA} + 0.1 \times \text{NWA} \qquad \text{(A-1)}$$

where: $1 \leq 10 \text{ percent NWA} \leq 10$

1.2 COST OF PUMPS

The cost of pumps in each well is calculated from the following equation:

$$\text{Cost per pump} = (30 \times \text{yield per well}) + 20{,}000 \qquad \text{(A-2)}$$

1.3 COST OF WELL CONSTRUCTION

The cost of well construction is calculated from the following equation:

$$\text{Cost per well} = (150 \times \text{depth of well}) - 2{,}200 \qquad \text{(A-3)}$$

1.4 COST OF INTERWELL PIPE

The cost of interwell pipe is related to peak flow rate and the number of wells by the following equation:

$$\text{Cost of interwell pipe} = 27{,}000(\text{peak flow rate} \times \text{number of wells})^{0.65} \qquad \text{(A-4)}$$

1.5 TOTAL COST OF WELLS

The total cost of the wells is equal to the cost of pumps plus the cost of interwell pipe plus the cost of well construction.

2.0 COST OF TRANSMISSION PIPE

2.1 SIZE OF PIPE

The pipe diameter is derived from a pipe-size optimization formula (Streeter, 1973). As pipe is available only in certain diameters, the size is rounded up to the next six-inch interval for $d_{in} \leq$ 48 inches (in) and rounded up to the next 12-in interval for $d_{in} > 48$ in. The value of d_{in} is given by the following equation:

$$d_{in} = 83.4 \times (P^{0.163} \times Q^{0.463})/(E^{0.163} \times C^{0.301}) \qquad \text{(A-5)}$$

where: P = Cost of electricity, $/kWh; Q = Peak flow rate, mgd;

E = Pumping plant efficiency; C = Hazen-Williams friction coefficient for pipe.

2.2 LENGTH OF PIPELINE

The length of pipeline to deliver water to a specific point outside the wellfield is equal to the miles of pipeline measured from a map times a factor ($\geq$ 1.0) to allow for terrain corrections.

2.3 COST OF PIPE

The cost per foot of pipe is derived from the transmission pipe cost taken from recent bids or construction summaries. Reinforced concrete pipe was assumed and the cost per foot of pipe is given by the following equations:

$$\text{Pipe Cost/ft} = 1.811 \times d^{in} - 8.945 \quad 12\text{-in} \leq d_{in} \leq 42\text{-in} \qquad \text{(A-6)}$$

$$\text{Pipe Cost/ft} = 4.015 \times d_{in} - 114.1 \quad 48\text{-in} \leq d_{in} \leq 90\text{-in} \qquad \text{(A-7)}$$

2.4 CONSTRUCTION COSTS

$$\text{Construction costs} = \text{cost of wells plus cost of pipeline} \qquad \text{(A-8)}$$

If booster stations, terminal storage and open channels are part of the system, the construction costs also include the costs of these facilities.

3.0 INTEREST DURING CONSTRUCTION

3.1 MONTHS FOR CONSTRUCTION

The construction period is determined using the following formula and applied to the design

capacity in mgd:

$$\text{No. of months (M)} = [8./(1./\text{mgd})^{0.32})], \text{ rounded up} \quad \text{(A-9)}$$

3.2 COST OF INTEREST DURING CONSTRUCTION

The cost of interest during construction is given by the following equation:

$$\text{Interest} = [((\text{Annual interest rate}/12.) \times M) \times (\text{Construction costs})] \quad \text{(A-10)}$$

4.0 ELECTRIC POWER COSTS

It takes 0.004 kWh to lift 1000 gallons of water one foot (Streeter, 1973). The annual cost of electric power is given by the following equation:

$$\text{Electric power costs} = \text{unit cost factor}[0.004 \times (\text{design capacity}/1000.) \times \text{head}] \quad \text{(A-11)}$$

$$\text{Head} = \text{Friction head} + \text{elevation head} + \text{height of tank} + \text{pumping lift} + \text{pump discharge head} \quad \text{(A-12)}$$

5.0 O&M LABOR, SUPPLIES AND MATERIALS

The cost of O&M labor, supplies and materials is related to peak flow rate, number of wells and miles of transmission pipe by the following equation:

$$\text{Cost of O\&M labor} = 3262(\text{peak flow in mgd} \times \text{no. of wells} \times \text{miles of transmission pipeline})^{0.49} \quad \text{(A-13)}$$

6.0 TOTAL O & M COSTS

Total O&M costs = Electric power costs + O&M labor, supplies and materials (A-14)

7.0 START-UP COSTS

The equation for start-up costs is given by:

$$\text{Start-up costs} = 0.0833 \times (\text{Total O\&M}) \qquad \text{(A-15)}$$

(Note: 0.0833 represents one month)

8.0 WORKING CAPITAL

The equation for working capital cost is given by:

$$\text{Working capital} = 0.1667 \times (\text{Total O\&M}) \qquad \text{(A-16)}$$

(Note: 0.1667 represents two months)

9.0 OWNER'S GENERAL EXPENSE

9.1 COST FACTOR

This cost factor is derived from the scaling factors given by Streeter (1973, p. 145), which vary with total construction cost (C), by the following equation:

$$\text{Factor} = (0.12/(1{,}000{,}000/C)^{-0.125}) \text{ for } C \leq \$10{,}000{,}000$$

or

$$\text{Factor} = (0.09/(10{,}000{,}000/C)^{-0.109}) \text{ for } C > \$10{,}000{,}000 \qquad \text{(A-17)}$$

9.2 OWNER'S GENERAL EXPENSE

Owner's general expense is given by the following equation:

$$\text{Owner's general expense} = C \times \text{Factor} \tag{A-18}$$

10.0 ANNUAL DEPRECIABLE CAPITAL COSTS

10.1 DEPRECIABLE CAPITAL RATE

Depreciable capital rate (DCR) is equal to the amortization factor plus interest rate plus tax rate plus insurance rate (Streeter, 1973, p. 178). The amortization factor plus interest rate equals the Capital Recovery Factor (CRF) which is derived from the equation given by Singh and others (1972, p. 11):

$$\text{CRF} = \text{Interest rate} \times (1. + \text{Interest Rate})^{N} / [(1. + \text{Interest rate})^{N-1}] \tag{A-19}$$

where: N = amortization period in years.

DCR = CRF + tax rate + insurance rate.

10.2 ANNUAL DEPRECIABLE CAPITAL COSTS

The depreciable capital cost (DCC) is given by the following equation:

$$\text{DCC} = \text{Total construction cost} + \text{Interest during construction} + \text{Start-up cost} + \text{Owner's general expense} \tag{A-20}$$

$$\text{Annual DCC} = \text{DCC} \times \text{DCR} \tag{A-21}$$

11.0 ANNUAL NON-DEPRECIABLE CAPITAL COSTS

Non-depreciable capital costs (NDCC) in the case studied here are equal to working capital because land costs are assumed to be zero on the RFP site. If land costs are included, then non-depreciable capital costs are land costs plus working capital. Annual NDCC is given by the following equation:

$$\text{Annual NDCC} = \text{NDCC} \times \text{Interest rate} \qquad \text{(A-22)}$$

12.0 TOTAL ANNUAL COSTS

Total annual costs are the sum of the annualized costs (Streeter, 1973) and are given by the following equation:

$$\text{Total annual costs} = \text{Total annual O\&M} + \text{Annual DCC} + \text{Annual NDCC} \qquad \text{(A-23)}$$

and

$$\text{Unit annual cost} = \text{Total annual cost/Design water use} \qquad \text{(A-24)}$$

13.0 INFLATION FACTOR

In program COST the following costs are multiplied by the inflation factor: total well costs and O&M labor, supplies and materials. For this study, the inflation factor was set equal to 1.

14.0 REFERENCES

Davis, C. V. and K. E. Sorensen [Editors], 1969, Handbook of Applied Hydraulics: New York, NY, McGraw-Hill Book Company.

Ramamurthy, G. and D. L. Chicoine, 1984, Capital Costs of Rural Water Systems: An Empirical Approach: Water Resources Bulletin, Vol. 20, No. 2, pp. 255-260.

Singh, K. P., 1971, Economic Design of Central Water Supply Systems for Medium Sized Towns: Water Resources Bulletin, Vol. 7, No. 1, pp. 79-92.

Singh, K. P. and others, 1972, Plans for Meeting Water Requirements in the Kaskaskia River Basin, 1970-2020: Illinois State Water Survey, Report of Investigations 70, 24 p.

Streeter, R. L., 1973, The Potential of Desalting for Industrial Water Supplies in Northeastern Wyoming: Office of Saline Water, Contract No. OSW 14-30-2975, June.

Whitlatch, R. L. and P. L. Asplund, 1981, Capital Cost of Rural Water Distribution Systems: Water Resources Bulletin, Vol. 17, No. 2, pp. 310-314.

Woodward-Clyde Consultants, 1975, Water Pumping and Transmission Cost and Analysis, PNM-EPE Site Selection Study Step 3e: Report prepared for Public Service Company of New Mexico and El Paso Electric Company, Project No. 74C 092C, July 21.

EG&G ROCKY FLATS

Rec'd - 11/4/91

INTEROFFICE CORRESPONDENCE

DATE: October 29, 1991

TO: Distribution

FROM: R. A. Applehans, Civil Engineering, Building 030, X3804

SUBJECT: ZERO OFFSITE WATER DISCHARGE STUDY, AIP ITEM C.7 TASK 30 (PREDECISIONAL CONSOLIDATION AND ZERO DISCHARGE PLANS) REVISION UPDATE RAA-130-91

PURPOSE

The purpose of this memo is to update previously issued *Task 30 - Predecisional Consolidation and Zero Discharge Plans* with the following attachments indicated below:

Item Description	Update	Replaces
Pages 3 and 4	9/30/91, Rev. 1	7/31/91, Rev. 0

RESPONSE REQUIREMENTS

If you have any questions or require further information regarding the above referenced, please advise.

RAA:swh

Attachment:
As Stated

Distribution
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F. A. Walker

Summary of Task Report Status

Task No. and Description[2)]	Report Status	Date
1 - Sanitary Sewer Infiltration/Inflow and Exfiltration Study	Final	9/30/91
2 & 3 - Storm Sewer Infiltration/Inflow and Exfiltration and Non-Point Source Study	Final	9/30/91
4 - Water-Yield and Water-Quality Study of Walnut Creek and Woman Creek Watersheds	Final	9/18/90
5 - Rainfall/Runoff Relationships Study	Final	6/18/91
6 - Storm-Runoff Quantity for Various Design Events Study	Final	1/08/91
7 - Solar Pond Interceptor Trench System Ground-Water Management Study	Final	1/15/91
8 - Present Landfill Area Ground-Water/ Surface-Water Collection Study	Final	1/15/91
9 - Design Recurrence Intervals Study	Final	8/28/90
10 - Sanitary Treatment Plant Evaluation Study	Final	1/08/91
11 & 13 - Treated Sewage/Process Waste-water Recycle Study	Final	1/08/91
12 - Reverse Osmosis and Mechanical Evaporation Study	Final	5/21/91
14 - Surface-Water and Ground-Water Rights Study in the Vicinity of the Rocky Flats Plant	Final	5/21/91
15 - Surface-Water Evaporation Study	Final	5/07/91
16 - Water-Yield and Water-Quality Study of Other Sources Tributary to Standley Lake and Great Western Reservoir	Final	12/18/90
17 - Alternatives to Zero-Discharge Study	Final	6/11/91
18 - Report on Drain Investigations	Final	6/25/91
19 - Process-Waste Minimization Study	Final	5/28/91
20 - Raw, Domestic, and Industrial Water Pipeline Leak Detection Method Study	Final	3/26/91
21 - Temporary Water Storage Capabilities Study	Final	3/19/91
22 - Ground-Water Recharge Study	None	--[1)]
23 - Study of Water Resource Management	Final	5/28/91
24 - Bypass Upstream Flows Around the Rocky Flats Plant Study	Final	1/15/91
25 - Study of Downstream Erosion Potential	Final	6/11/91
26 - Feasibility of Ground-water Cutoff/Diversion Study	Final	5/21/91

Summary of Task Report Status - continued

Task No. and Description[2]	Report Status	Date
27 - Waste-Generation Treatment Study	Final	6/04/91
28 - Augmentation Plan for the Rocky Flats Plant	Final	6/30/91
29 - Non-Tributary Ground-Water Study	Final	5/21/91
30 - Consolidation and Zero-Discharge Plans	Interim Draft	9/28/90
	Final Draft	6/25/91
	Predecisional	7/31/91[3]

1) No date set because of delays in obtaining excavation and work permits related to field efforts (ASI, Task 22, 1990ee).
2) Adapted from (ASI, 1990a).
3) Extended review and comment period.

The results of the individual study tasks are not summarized in this report. The reader is encouraged to refer to the subordinate task studies and other water-management activities for more detail on areas of particular interest.

The consolidation section of this report summarizes the interconnections between the individual task studies as well as other related DOE and EG&G activities. As a basis for understanding the need for a zero-discharge plan, a summary of the current regulatory framework is summarized. The consolidation section also summarizes the approaches taken toward consolidation of task and zero-discharge plans.

The zero-discharge plans portion of this report is based upon the results of the 30 subordinate task studies. Selected definitions of zero discharge are used to formulate alternatives, including the "No-Action" Alternative. One or more of these proposed zero-discharge alternatives could constitute a zero-discharge plan, depending upon the definition of zero discharge.