QUINSAM COAL LIMITED

HYDROGEOLOGIC EVALUATION
QUINSAM AREA
CAMPBELL RIVER, B.C.

BROWN, ERDMAN & ASSOCIATES LTD.
NORTH VANCOUVER, BRITISH COLUMBIA

HYDROGEOLOGIC EVALUATION

QUINSAM AREA

British Columbia, Canada

for

QUINSAM COAL LTD.

by

W. L. Brown, P. Eng.

May 1979

Brown, Erdman & Associates Ltd.
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EXECUTIVE ABSTRACT

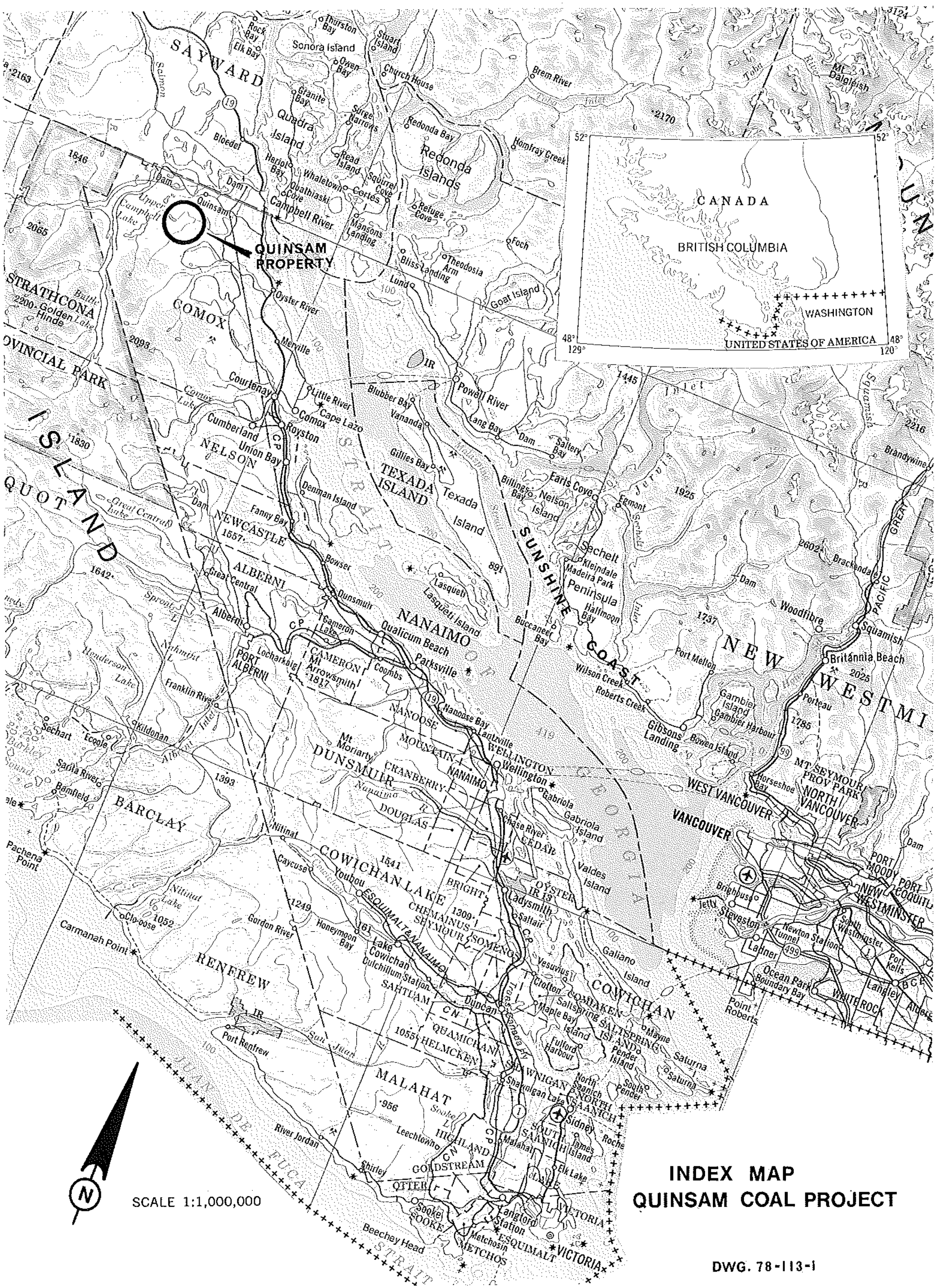
This report is a compilation of the hydrogeologic information contained in published and unpublished reports. The interpretations contained herein are also based upon field and air photo studies and upon practical experience gained from groundwater exploration and development projects in the area of interest and along the Coastal Lowlands of eastern Vancouver Island.

The hydrogeology of an area of approximately 600 square kilometers (215 square miles) is described. This area is bounded by the Campbell River in the north, the Oyster River in the south, the Campbell Lakes to the west and the Strait of Georgia to the east.

Six community water systems exist in this area. Private water systems are supplied from 405 known springs and wells. None of these community or private systems will be affected by coal mining in the Middle Quinsam Lake area.

All groundwater in the mine site will be intercepted, collected and treated to a quality equal to or better than the ultimate receiving waters and returned to the Quinsam River system. Therefore neither the quality nor the quantity of those waters within the Quinsam River system will be affected. In turn the Fish Hatchery on the lower Quinsam River which uses spring water will not be affected by mining.

The hydrogeologic system in the area of the pits will essentially return to its natural condition within a year after mining stops.



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INDEX MAP
QUINSAM COAL PROJECT

DWG. 78-113-1

1.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon data presently available to us we conclude that:

1.1 The hydrogeologic conditions beyond 300 meters (1000 feet) from the pits will not be adversely affected either during or after mining. Some perimeter well dewatering may be required during mining. In addition, natural dewatering of surrounding aquifers will take place through the use of sumps and ditches in the proposed open pits.

1.2 The flows of water in the surface streams and rivers will not be affected by the dewatering of the fractured bedrock or glacio-fluvial gravel filled channels during mining because the groundwater will be treated and returned to the Quinsam River system.

1.3 No known water source (public or private) exists closer than 14 kilometers (8.5 miles) to the Middle Quinsam Lake pits.

1.4 No known water source will be polluted or contaminated by the proposed mining activity.

1.5 Because the groundwater removed during dewatering will be treated and returned to the Quinsam system, the quality and quantity of the water in the Quinsam River will not be adversely affected so that the Fish Hatchery located near the confluence of Cold Creek and Quinsam River will not be adversely affected.

1.6 Prior to mining a local groundwater testing program must be conducted to establish the hydrogeologic parameters required to design site specific dewatering and water treatment systems. Such a program will take six months to complete.

1.7 There is sufficient hydrogeologic and surficial geologic data presently available for the present stage of the project.

2.0 INTRODUCTION

2.1 General Statement

Quinsam Coal Ltd. proposes to mine coal in the Middle Quinsam Lake area of Vancouver Island. The development area will cover approximately 1700 hectares (4000 acres) and contains 14 million tonnes (15.2 million tons) of proven surface mineable reserves and an additional 16.4 million tonnes (18.0 million tons) of underground reserves for a total of 30 million tonnes (33 million tons). In addition, another 8.6 million tonnes (9.45 million tons) of probable surface mineable reserves are present in the Quinsam East Block.

This report describes the hydrogeology of the development and adjoining areas. It is based on a compilation of public and private reports (please see References), air photo and field studies, and general experience gained from groundwater developments along the eastern lowlands of Vancouver Island. As such this report should meet the preliminary requirements of those parts of the Guidelines for Coal Development that refer to Groundwater and Surficial Geology.

2.2 Location and Extent

The Middle Quinsam Lake development area is located 180 kilometers (110 miles) northwest of Vancouver, 225 kilometers (135 miles) north-northwest of Victoria and 20 kilometers (12 miles) west-southwest of Campbell River. Please refer to Index Map 78-113-1 and Location Map 78-113-2. The area covered by this report lies between the Campbell and Oyster Rivers, extends eastward from the Campbell Lakes to the Strait of Georgia, and covers an area of approximately 600 square kilometers (215 square miles).

2.0 INTRODUCTION continued

2.3 Physiography

The report area lies predominantly in the Coastal Lowland physiographic division. The Coastal Lowland is approximately 9 kilometers (5.5 miles) wide in the Quinsam Lake area and is the unsubmerged southwestern edge of the Coastal Trough which is largely occupied by the Strait of Georgia. The Vancouver Island Ranges extend into the western part of the map area. The boundary between the Vancouver Island Ranges and the Coastal Lowland varies in altitude from 215 to 305 meters (700 to 1000 feet) and is generally the contact between the shales and sandstones of the Nanaimo Group and the volcanic and granitic basement rocks.

The topography is undulating and subdued. Numerous examples of ice contact features such as drumlins, crag and tail, eskers, kettles and abandoned meltwater channels are present to the east and north of the coal deposits. Please see Geology Compilation Map 78-113-3.

2.4 History

The recorded history of the area starts with the arrival of Captain George Vancouver in the inland waterways between Vancouver Island and the Mainland in May 1792. Campbell River was named after Dr. Samuel Campbell, a surgeon on the British Surveying Ship HMS Plumper and first appears on the Great Britain Admiralty Hydrographic Chart dated 1860. Prior to the arrival of the white man, a large village of Kwakiutl Indians was located in what is now known as Campbell River. These Indians moved to the Quinsam flats (now Quinsam I.R.12) each fall to catch salmon. Small pox and measles so severely decimated these Indians that the

2.0 INTRODUCTION continued

2.4 Continued

village was abandoned some time in the late 1880's and the survivors moved to Cape Mudge on Quadra Island.

Homesteads were established along the coast by the turn of the century. Five preemptors who occupied lands between the Oyster and Campbell Rivers were registered by 1900. Logging followed and a store and hotel were erected in 1904 when Campbell River became a permanent settlement.

The coal beds beneath the low lying lands of the Quinsam and Campbell Rivers were known to exist prior to 1913 and were explored by numerous borings. Canadia Collieries Ltd. drilled 30 bore holes in the area between 1945 and 1960.

The coal deposits of the Middle Quinsam Lake area were not discovered and explored until the 1970's.

The first water system was built at Campbell River in 1916 to supply the store, hotel and a few residences. A spring was the source of water. The rest of the area was supplied with water from individual wells. The present water system obtains its supply of water from one of the penstocks at the John Hart Dam and was started in 1949 with 450 connections. The Greater Campbell River Water Board was formed in 1962 and by 1975 had almost 5000 connections.

2.5 Climate

Six weather stations are presently in operation in the subject area. These stations are: (Please see Location Map 78-113-2).

2.0 INTRODUCTION continued

2.5 Continued

Station	Elevation meters	(feet)
Campbell River A (airport)	105	(346)
Campbell River BCFS (forest service)	128	(420)
Campbell River BCHPA Gen (B. C. Hydro)	30	(100)
Duncan Bay	7	(22)
Oyster River UBC	11	(35)
Quinsam River Hatchery	46	(150)

The mean monthly and total mean annual precipitation for these stations are shown on Table I.

The Campbell River-Oyster River Lowland area has a maritime climate with an average total annual precipitation of 1520 millimeters (60 inches), approximately 1750 hours of sunshine, a 180 day growing season and a water deficiency during vegetative period of 180 millimeters (7 inches) (Reference 4). The water deficiency of 180 millimeters (7 inches) and the calculated potential evapotranspiration of approximately 360 millimeters (14 inches) indicates that irrigation is essential to good crop growth. Numerous water wells in the area supply irrigation water to farms near the coast.

TABLE I

MEAN PRECIPITATION

CAMPBELL RIVER AREA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
CAMPBELL RIVER AIRPORT EL. 105 m 1965 - 1977													
mm	186.2	128.3	150.1	59.4	51.1	39.1	37.8	41.9	53.6	162.1	222.5	255.5	1387.9
in.	7.33	5.05	5.91	2.34	2.01	1.54	1.49	1.65	2.11	6.38	8.76	10.06	54.64
CAMPBELL RIVER B C F S EL. 128 m 1969 - 1977													
mm	198.4	178.3	168.1	66.3	72.6	54.6	48.0	53.3	77.2	174.8	252.2	262.1	1549.7
in.	7.81	7.02	6.62	2.61	2.86	2.15	1.89	2.10	3.04	6.88	9.93	10.32	61.01
CAMPBELL RIVER B C H P A EL. 30 m 1973 - 1977													
mm	202.7	181.8	181.4	46.3	87.5	52.2	52.2	55.2	47.6	197.2	231.0	252.5	1500.9
in.	7.98	7.16	7.14	1.82	3.45	2.05	2.06	2.17	1.87	7.76	9.09	9.94	59.09
DUNCAN BAY EL. 7 m 1957 - 1977													
mm	233.9	168.1	157.0	75.4	60.7	52.8	45.5	53.8	76.2	198.4	236.5	297.2	1660.1
in.	9.21	6.62	6.18	2.97	2.39	2.08	1.79	2.12	3.00	7.81	9.31	11.70	65.36
OYSTER RIVER U B C EL. 11 m 1967 - 1977													
mm	182.6	121.7	142.5	56.4	42.7	34.5	34.3	34.8	53.1	151.9	219.7	249.4	1331.0
in.	7.19	4.79	5.61	2.22	1.68	1.36	1.35	1.37	2.09	5.98	8.65	9.82	52.40
QUINSAM RIVER HATCHERY EL. 46 m 1975 - 1977													
mm	155.3	122.4	159.3	59.4	89.5	31.9	44.3	60.3	45.6	226.4	248.1	165.9	1290.1
in.	6.12	4.82	6.27	2.34	3.53	1.26	1.75	2.38	1.80	8.91	9.77	6.53	50.80

2.0 INTRODUCTION continued

2.6 Acknowledgments

The assistance given by Mr. E. C. Halstead of the Hydrology Research Division, Inland Water Directorate Environment Canada, is gratefully acknowledged. Mr. Halstead allowed us access to his extensive files on the hydrogeology of the subject area. Dr. J. C. Foweraker, Head, Groundwater Section Hydrology Division, Water Investigation Branch, Ministry of the Environment (B. C.), expeditiously supplied well records and well location maps for parts of the subject area. His assistance is gratefully acknowledged.

3.0 WATER USE

3.1 Community Water Systems

Six community water systems exist in the area of interest. These are:

System	Source
Black Creek-Oyster Bay (Water Specified Area)	Well (Miracle Beach area) - not operational
Greater Campbell River Waterworks	John Hart Lake
North Campbell River Waterworks	John Hart Lake
Quinsam Heights Waterworks	John Hart Lake
Quinsam Indian Reserve #12	Well (16 feet deep)
Watutco Enterprises Ltd. (supplies small residential subdivison)	Oyster River
Willow Point Waterworks	Erickson Creek

These systems are shown on Location Map 78-113-2.

It will be noted that the main systems obtain their water from John Hart Lake which cannot be affected in any way by the proposed Middle Quinsam Lake coal mining operation. The Black Creek-Oyster Bay system will obtain its water from wells. One well will produce at a rate of approximately 22 litres per second (300 gallons per minute) and is located near the mouth of the Oyster River approximately 15 kilometers (9 miles) from Quinsam East Block and 25 kilometers (15 miles) from the North and South pits near Middle Quinsam Lake. Other wells are being drilled to the south of Oyster River and will be located much farther away from the proposed mining areas.

3.0 WATER USE continued

3.1 Continued

Willow Point Waterworks obtains its water from Erickson Creek. The intake lies approximately 18 kilometers (11 miles) from the North and South pits. The headwaters of Erickson Creek is a swamp that lies 12 kilometers (7 miles) from these pits.

The source of water for the Watutco Enterprises Ltd. system is from the Oyster River. The water is apparently of inferior quality during the late summer and fall. It is rumored that the system is seeking water from or is trying to join the Black Creek-Oyster Bay Specified Area. Although the Watutco Enterprises Ltd. system could be affected by mining in the Quinsam East Block if they join the Black-Creek-Oyster Bay Specified Area system they will obtain their water from wells to the south of Oyster River so that they cannot be affected by coal mining.

3.2 Private Water Sources

The number of private water sources recorded in the map area by the Groundwater Division (B. C.) are as follows:

Dug wells	320
Drilled wells	57
Springs	28
Total	405

Representative wells are shown on Table 2.

If we assume that the water demand on each well and spring averages 3300 litres (720 gallons) per day then the 405 private water sources will withdraw 1.34 million litres (0.3 million gallon) per day. Since the

TABLE II

REPRESENTATIVE WELL RECORDS

CAMPBELL RIVER AREA

WELL NO.	DEPTH m	STATIC LEVEL, m	AQUIFER TYPE	REMARKS
1	106.7	—	Clay, sand, gravel	Test hole dry - abandoned
2	160.0	—	Clay, till	Test hole abandoned
3	5.5	2.1	Bedrock	High Fe and H_2S odor
4	7.6	—	Silt, clay	Quantity low in summer
5	35.0	5.5	Sandstone, shale	Yield 0.63 lps
6	8.8	—	Shale	Test hole abandoned
7	25.9	1.2	Sand 6.7 - 9.8 m	Test hole abandoned
8	28.0	3.0	Sand, gravel 13.4 - 14.6, 18.6 - 20 m	Test hole abandoned
9	19.5	—	Clay, till	Test hole dry - abandoned
10	30.2	1.2	Gravel 28.3 - 30.2 m	Test hole abandoned
11	20.4	3.0	Fine sand 13.1 - 20.4 m	Yield 1.26 lps
12	31.4	4.9	Bedrock	Quality saline
13	30.5	1.2	Gravel 28.3 - 30.5 m	Test hole abandoned
14	9.8	2.6	Gravel 8.8 - 9.8 m	Test hole abandoned
15	46.9	—	Bedrock	Dry hole abandoned
16	30.5	—	Bedrock	Dry hole abandoned
17	13.1	1.7	Fine sand 12.2 - 13.1 m	Yield 0.37 lps
18	7.0	3.8	Sand, gravel 4.0 - 6.7 m	Yield 0.63 lps
19	30.5	—	Till 1.8 - 5.2 m	Yield 0.13 lps
20	61.0	9.1	Shale	Yield 0.32 lps
21	166.1	—	Shale	Quality saline
22	22.9	2.4	Shale, sandstone	Yield 1.58 lps

For locations of the above wells please see Location Map 78-113-2

3.0 WATER USE continued

3.2 Continued

water users are on septic tanks and use most of their water for irrigation of vegetable and flower gardens and lawns, the actual net removal of water from the ground will probably be less than one-third of this amount or 450,000 litres (100,000 gallons) per day. This will amount to 165 million litres (36 million gallons) per year. This is equivalent to 6 litres per second (80 gallons per minute).

The majority of the domestic wells are located in the semi-rural development within 300 meters (1000 feet) of the Island Highway and the seashore with one notable exception. In the Campbell River area wells extend 2.5 kilometers (1.5 miles) inland from the coast. The closest known well to the proposed coal mining area is the well at the Campbell River Airport which lies 13 kilometers (8 miles) to the east of the proposed North and South pits. This well obtains its water from fine grained water-bearing sands that lie between depths of 13 meters (43 feet) and 20 meters (67 feet) beneath clays, compact silts and silty fine sand. These overlying sediments have very low permeabilities and will protect the water-bearing zones from contamination or pollution by surface or near surface waters. The airport well <u>will not be affected</u> by the proposed mine.

3.3 Irrigation

The experimental farm operated by the University of British Columbia obtains its domestic, stock and irrigation water from a well with a productive capacity of 45 litres per second (700 gallons per minute) and a depth of 11.6 meters (38 feet).

3.0 WATER USE continued

3.4 Fisheries

The Fish Hatchery located on the Quinsam River immediately upstream from its confluence with Cold Creek (please see Location Map 78-113-2) is supplied with water from an intake located on the south fork of Cold Creek. The south fork of Cold Creek above its confluence with the north fork is spring-fed. The flow increases from 28 litres per second (3 cubic feet per second) to 956 litres per second (34 cubic feet per second) over a length of stream valley of 1000 meters (3000 feet). The flow of these springs reportedly increased significantly after the reservoir behind the dams on the Campbell Lakes system filled. Fears that spring sapping would breach the natural sand and gravel dam on the east side of McIvor Lake were unfounded. As will be discussed in a later section, the waters supplying the springs and the Hatchery come from the Campbell Lakes system which will not be affected by the proposed coal mines. However, since the Hatchery uses the Quinsam River to catch and release its fish it will be necessary to show that the quality and quantity of the Quinsam River water will not be materially affected. The Hatchery is located approximately 30 kilometers (18 miles) downstream from the proposed North and South pits.

The Rosewall River Hatchery is located approximately 60 kilometers (35 miles) to the southeast of the mouth of the Oyster River. It is supplied by water from wells located on the premises. As such it is so far away from the proposed mining sites that it will be totally unaffected by the proposed project.

3.0 WATER USE continued

3.5 Effect of Mining

As noted above, the proposed operation will not affect the present public and private water sources with the possible exception of the Watutco Enterprises Ltd. water system. This system with its intake on the Oyster River could be affected by Quinsam East Block operations.

3.6 Future Groundwater Use

The existing water systems are being upgraded by the construction of new water wells to meet the ever increasing demand for water. New systems obtaining their water from wells are being constructed. Some of the communities along the sea coast and the Island Highway (19) are experiencing a 9% annual growth rate during a slow economic period. This doubling of the population every nine years will mean that more and more water wells will be needed. However, as the population grows, private domestic wells are abandoned as more people connect to the public systems. Thus, the chance of polluting or contaminating the groundwater reservoirs diminishes as more sophisticated properly designed wells are constructed under carefully controlled conditions.

4.0 GROUNDWATER GEOLOGY

4.1 Basement Rocks

Reference to the Geology Compilation Map No. 78-113-3 will show that the basement rocks underlying and adjacent to the coal-bearing sedimentary rocks consist of Upper Triassic interbedded tuffs and basaltic flows, a series of Upper Triassic or lower Jurassic interbedded tuffs, andesitic flows, breccias, and siltstones, and Jura-Cretaceous granodiorite of the Coast Intrusions.

The groundwater characteristics of the so-called Vancouver Group of altered interbedded tuffs and flows have been investigated over a wide area on Bowen Island, the Sunshine Coast, and Vancouver Island. Please see Index Map 78-113-1. In general the groundwater-bearing characteristics of these rocks are poor. Wells 90 to 150 meters (300 to 500 feet) deep have been drilled in the areas mentioned with capacities of less than 0.6 litres per second (8 gallons per minute). Even though wells drilled through these volcanic rocks intersect fracture zones at depth, their productivity remains very low. This low productivity is caused by secondary mineralization (calcite and epidote) and rock flour that plugs the fractures combined with an extremely small intergranular permeability.

We believe that the rock series in the proposed mining area will have the same poor groundwater-bearing characteristics as those series examined in the areas mentioned above.

The granodiorites of the Coast Intrusions have been extensively explored on Saanich Peninsula, Bowen Island, and on the end of Nanoose Peninsula (120 kilometers or 72 miles south of mine site). When wells drilled into these granodiorites encounter fracture zones they are usually moderately productive. In places these rocks are so highly fractured

4.0 GROUNDWATER GEOLOGY continued

4.1 Continued

that they behave like gravels when being drilled and must be cased as drilling proceeds. Ninety to 150 meter (300 to 500 foot) deep wells are capable of producing up to 18 litres per second (240 gallons per minute). Our experience indicates that the average productivity of properly located (with respect to tension fractures adjacent to fault zones) and constructed wells up to 150 meters (500 feet) deep will be 4 litres per second (50 gallons per minute).

A detailed groundwater drilling and testing program for the design of an open pit dewatering system in similar granodiorites in the interior of British Columbia showed that the centres of fault zones form groundwater dams while the tension zones adjacent to the faults form conduits. A change in hydrostatic head of 9 meters (30 feet) was noted across a fault that was transversely oriented to the groundwater flow.

These Triassic to Cretaceous rocks are present in tilted fault blocks in the area adjacent to the proposed mine. The main fault systems trend northwest, east northeast and east-west.

4.2 Coal-bearing Sediments

The Nanaimo Group of Upper Cretaceous age consists of the Benson Conglomerate overlain by the Comox formation of interbedded sandstones, shales and coal. The conglomerate mainly occurs along the Oyster River suggesting an ancient valley fill. The thickness varies from a few centimeters to more than 150 meters (500 feet).

4.0 GROUNDWATER GEOLOGY continued

4.2 Continued

The Comox formation was deposited in an essentially non-marine lagoonal environment and varies from 60 meters (200 feet) to 300 meters (1000 feet) in thickness. In the Middle Quinsam Lake area the Comox formation is generally 60 meters (200 feet) thick. Reference to the stratigraphic column over leaf will show that the Comox formation in the area of interest contains three coal seams ranging from 30 centimeters (one foot) to 5 meters (15 feet) in thickness separated by sandstones and siltstones. Minor beds of mudstone are associated with the coal seams.

The Comox beds in the mine area are gently dipping (3° to 17°) to the northeast and are contained in a series of down faulted blocks. The main faults are normal and trend northwest. Brittle fracturing is dominant. Folding and thrust faulting are insignificant.

The water-bearing characteristics of the Comox formation are not well known in the area of interest. However, lithologically similar sandstones and mudstones have been studied further south throughout the Gulf Islands from Nanaimo to Victoria. A special groundwater exploration drilling and testing program was conducted for the Groundwater Division (B. C.) on Gabriola Island in 1973 (see Reference 28).

The groundwater productivity of the Cretaceous sandstones and shales is generally poor to moderate. Sufficient water to supply a family unit can be obtained above a depth of 90 meters (300 feet) almost anywhere in these sediments. Groundwater enters the wells from fractures, bedding planes, and slip fractures

4.0 GROUNDWATER GEOLOGY continued

4.2 Continued

or cleavages within the silt and mudstones. In places where these rocks have been affected by major faults they have been turned into slates with the presence of water-bearing slaty cleavages. The sandstones are moderately productive where fractured. Properly located, designed, constructed and stabilized wells 90 meters (300 feet) deep should be capable of producing at rates of from 1.5 litres per second (20 gallons per minute) to 4 litres per second (50 gallons per minute). Wells drilled to deeper depths should have safe productive capacities up to 8 litres per second (100 gallons per minute).

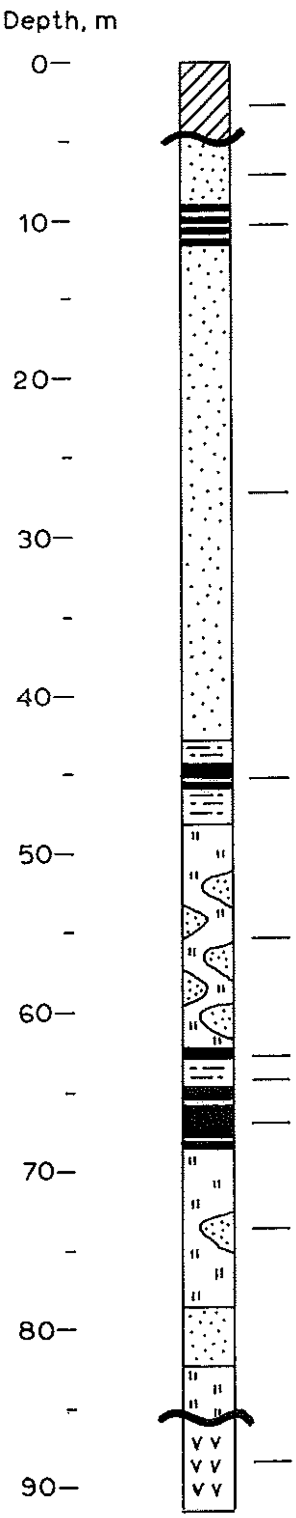
4.3 Surficial Deposits

4.3.1 Regional

The surficial deposits of the coastal lowlands consist of the following basic units:

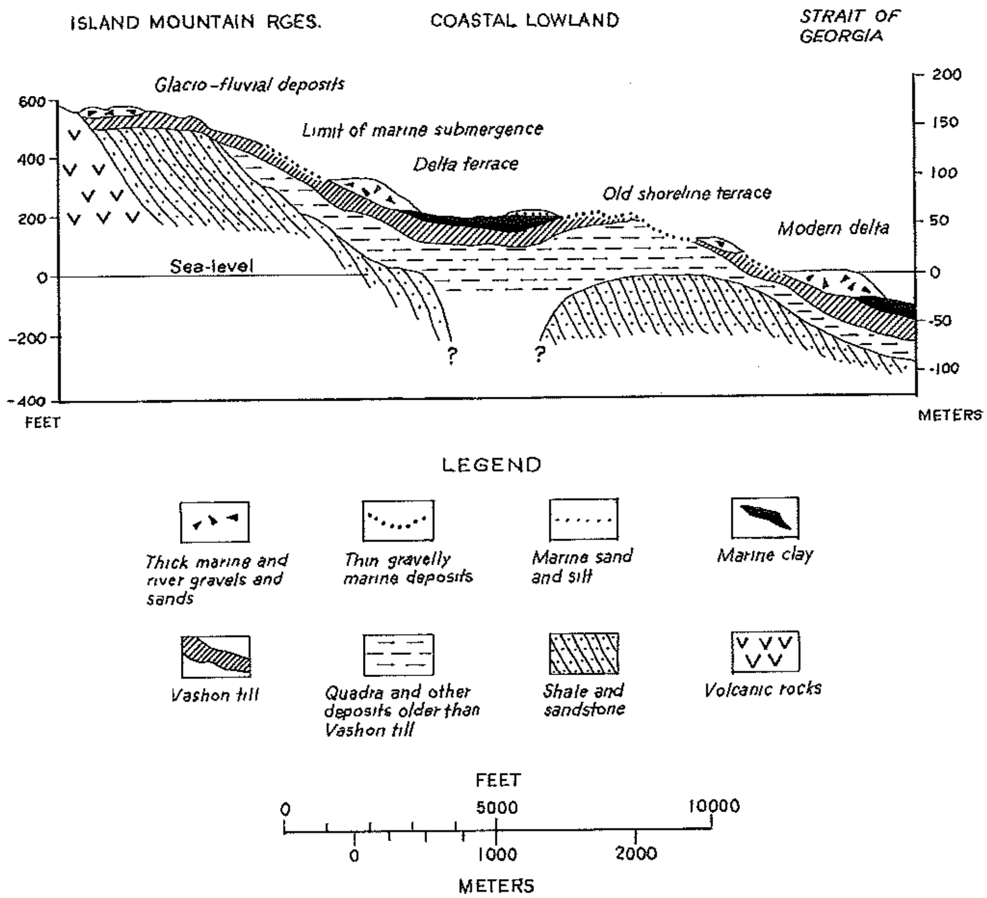
Map Units		Maximum Thickness (meters)
5, 6, 7, 8	Post-glacial marine and fluvial deposits.	25
3, 4	Glacial till and glacio-fluvial deposits.	30
2	Non-glacial sands, silts and clays with peat, wood and marine shells.	110
	Glacial till.	25
	Non-glacial sand, silt and clay.	15 plus

Statigraphic Column
Comox Formation
Quinsam Coal Project



Unit	Thickness, m	Lithology
	0 - 4.6	Compacted and cemented clay with boulders.
		Sandstone, m.-gr., arkosic.
	3.7 - 4.6	1.8 m - 3.0 m coal with 3 partings.
	30.5 - 39.6	Sandstone m.-cs.gr. arkosic massive, minor siltstone and mudstone partings.
	0.3 - 1.5	0.3 m - 1.6 m coal with 1 parting.
	18.3 - 24.4	Interbedded dk. grey siltstone with greenish grey sandstone.
	0.3 - 0.6	0.3 m - 0.5 m coal.
		Mudstone.
	3.0 - 4.9	2.0 m - 3.7 m coal with 3 minor partings.
	0 - 18.3	Primarily dk. grey siltstone with green sandstone lenses, red siltstone at base.
		Metavolcanics argillites.

Modified from: Weldwood of Canada Limited and Luscar Ltd.
1978: Quinsam Coal Project; a Joint-Venture Proposal - Reference 23.



Diagrammatic section looking northwest showing material beneath the Eastern Coastal Lowland, Vancouver Island. Relationships shown are typical of the country between Lantzville and Campbell River.

Modified from Halstead, E. C. and Treichel, A. 1966: Groundwater Resources of the Coastal Lowland and Adjacent Islands, Nanoose Bay to Campbell River, East Coast, Vancouver Island; Geol. Surv. Can., Bull. 144. Reference 8.

4.0 GROUNDWATER GEOLOGY continued

4.3 Continued

4.3.1 The total maximum thickness of these deposits probably exceeds 250 meters (820 feet). A well on the delta of Campbell River drilled through 154 meters (505 feet) of sands, tills and clays before encountering bed-rock. Although information is meager north of the Oyster River a buried bedrock channel running sub-parallel with the coastline probably exists within 4 kilometers (2.5 miles) of the coastline. The presence of this channel is well established to the south of Oyster River.

Mapleguard Sediments - Please see the diagrammatic sketch on the preceding page which shows the generalized relationship of the various lithologic units. The lowermost unit of non-glacial sediments is known as the Mapleguard Sediments and is observable at the base of sea cliff exposures 75 and 90 kilometers (45 and 54 miles) southeast of the mine site. They are present in the lower portions of the well drilled on the Campbell River delta. Little is known about the groundwater characteristics of these sediments.

Dashwood Drift - The lower glacial deposits of till and associated glacio-fluvial sands and gravels are known as the Dashwood Drift deposits. These deposits are observable on sea cliffs to the south of the area of interest. These drift deposits will produce sufficient water to wells for domestic purposes through fractures and flaky cleavage planes.

4.0 GROUNDWATER GEOLOGY continued

4.3 Continued

4.3.1 Quadra Sediments - The non-glacial sediments have been named the Quadra Sediments and consist of the following main lithologic units:

- White sand (minor gravels and silts).
- Plant-bearing silt, gravel and sand.
- Marine, stony and laminated clays.

The white sand unit is known to be highly productive of groundwater although careful screening, filtering and developing (cleaning) techniques are required. This unit will be found to fill the bedrock channel described above.

Vashon Drift - The glacial till and its attendant glacio-fluvial deposits have been assigned to the Vashon glaciation named for Vashon Island in northwestern Washington State. The Vashon till is widely exposed at or near ground surface over most of the map area. The glacio-fluvial deposits with their ice contact features of kettles, eskers and deltas are well exposed in the McIvor and John Hart Lake area and in the Quinsam East Block areas. It will be noted that a number of gravel pits (active or abandoned) are present in these deposits.

The Vashon till yields small amounts of groundwater to dug wells through sand and gravel lenses, joints and the flaky pie crust structure so common in this till sheet. In places the dug wells are essentially cisterns that

4.0 GROUNDWATER GEOLOGY continued

4.3 Continued

4.3.1 store the winter rainwater for use during the summer drought. The glacio-fluvial sands and gravels are highly permeable and highly productive to both dug and drilled wells. These are the sands and gravels that transmit water from McIvor Lake to the springs along the south fork of Cold Creek which supply water to the Fish Hatchery located on the lower Quinsam River.

The post-glacial marine deposits consist of clay, silts and slope wash stony clays. As such they are low producers of groundwater. The post-glacial deltas, river gravels and raised beaches are highly productive aquifers.

4.3.2 <u>Local</u>

The surficial deposits of the mine area consist of glacial till, glacio-fluvial sands and gravels, aeolian silts and colluvium. A reddish brown pebbly loam less than one meter (3.28 feet) thick mantles the area.

The thickness of the surficial deposits is known (from exploration holes) to range from 0 to almost 50 meters (165 feet). The thickest deposits are contained in a buried river valley that separates pits 2N and 3N. It trends northeast-southwest in the vicinity of the pits and the dump. Although no drill hole control exists to the east of the pit area, air photo studies indicate that the channel swings to an

4.0 GROUNDWATER GEOLOGY continued

4.3 Continued

4.3.2 east-west orientation and could underlie the present valley of the Quinsam River in the eastern part of the map. Please refer to Map 78-113-4. Other channels most probably exist that are mainly coincident with Long Lake, Iron River and Middle Quinsam Lake.

The glacio-fluvial sands and gravels contained in these channels will be highly permeable and capable of yielding large amounts of groundwater to wells.

The piezometric surface map (Map 78-113-5) shows that the groundwater flows from topographic highs to topographic lows. It also shows how the highly permeable sands and gravels in the buried channel between pits 2N and 3N cause a pronounced low in the piezometric surface.

Maps 78-113-4 and 78-113-5 were difficult to draw because of concentrated data in the area of the pits and an observed (on the ground and on air photos) complexity of the topography. Hills and ridges with bedrock at ground surface are separated by narrow valleys containing several meters of unconsolidated deposits.

The surficial deposits in the East Quinsam Block consist of glacial till with overlying glacio-fluvial sands and gravels forming surface eskers.

5.0 GROUNDWATER HYDROLOGY

5.1 Assumed Parameters

No field or laboratory tests have been conducted on the various rock types present within the mining area. The magnitude of the various parameters used in the following sections of the report have therefore been assumed. The assumptions are based predominantly upon field test results conducted on the same or similar rocks throughout British Columbia. The degree of accuracy necessary to prognosticate groundwater flow rates and to design dewatering systems is discussed in Section 5.2. It will be shown that the change of a parameter by a factor of 2 will have little practical significance primarily because geologic unknowns, particularly within the geometry of the surficial deposits, will outweigh mathematical accuracy.

5.1.1 Permeabilities

The various rock types present in the area and their assumed permeabilities are shown below.

Vancouver Group

Altered tuffs and flows	
- non-fractured	1×10^{-8} cm/sec
- fractured	1×10^{-6} cm/sec

Coast Intrusions

Granodiorite	
- non-fractured	1×10^{-8} cm/sec
- fractured	5×10^{-5} cm/sec

Comox Formation

Sandstone	
- non-fractured	5×10^{-6} cm/sec
- fractured	1×10^{-4} cm/sec

5.0 GROUNDWATER HYDROLOGY continued

5.1 Continued

5.1.1 Comox Formation continued

Shale, Siltstone		
	- non-fractured usually with cleavage planes	5×10^{-5} cm/sec
	- fractured	1×10^{-4} cm/sec

Surficial Deposits

Clay		
	- desiccated with joints	1×10^{-5} cm/sec
	- non-desiccated	1×10^{-6} cm/sec
Silt		
	- bedding planes, sand partings	1×10^{-4} cm/sec
Till		
	- flaky cleavage	1×10^{-4} cm/sec
Sands and Gravels		
	- silty	1×10^{-3} cm/sec
	- clean	2×10^{-1} cm/sec

5.1.2 Storage Factor (or Storativity)

This is a dimensionless characteristic of aquifers which is defined as the volume of water released or taken into storage, per unit of surface area of the aquifer per unit change of head. Under normal water table or unconfined conditions it essentially equals the porosity of the groundwater-bearing sediments minus the pellicle water held by capillary and molecular attraction around the grains. Thus, it is equal to the "effective porosity" of the aquifer.

5.0 GROUNDWATER HYDROLOGY continued

5.1 Continued

5.1.2 Under confined conditions, particularly in fractured rocks, the storage factor becomes very low. Consequently the following storage factors will be used:

Unconfined or Non-artesian Conditions

Sands and gravels	0.2	(effective porosity 20%)
Fractured rocks	0.01	

Confined or Artesian Conditions

Sands and gravels	0.001
Fractured rock	0.0001

5.1.3 Gradients

Experience indicates that the groundwater table under non-artesian conditions and the piezometric surface under artesian conditions will be sub-parallel to the ground surface. The lower the permeability becomes and the higher the recharge becomes the closer these surfaces come to be truly parallel to each other.

The regional gradients across the coastal lowlands of subdued relief will slope towards the sea coast with a gradient of approximately one to fifty. Where recharge into permeable sands and gravels is taking place from lakes the gradients will steepen to one in twenty and one in ten.

The local gradients in the mine areas can be seen on Map 78-113-5 to be as steep as approximately one to ten and as flat as approximately one to fifty.

5.0 GROUNDWATER HYDROLOGY continued

5.2 Calculations (used to analyse the effects of dewatering)

5.2.1 Basic Formulae

For convenience a list of symbols are given below before the formulae are discussed.

T - transmissivity gpd/ft

Q - discharge gpm

S - storage factor - dimensionless

r - radius - feet

t_o - intercept of fitted line on semi-logarithmic paper with zero drawdown in days

K - drawdown factor from 1952 Theis Chart - dimensionless

DD - drawdown - feet

t - time since pumping starts - days or minutes, as required.

The basic formulae for the calculations of the groundwater parameters from pump test data are:

Transmissivity (T) - use drawdown or recovery water level measurements plotted against time in minutes since pumping started or stopped on semi-logarithmic paper, fit the best straight line or lines and use the following formula:

$$T = \frac{264 \times \text{discharge } Q \text{ (gpm)}}{\text{slope per log cycle (feet)}}$$

(Jacob method)

5.0 GROUNDWATER HYDROLOGY continued

5.2 Continued

5.2.1 Use drawdown water level measurement in pumped well and observation wells plotted against distance in feet on semi-logarithmic paper for any fixed period of time, fit the best straight line, and use the following formula:

$$T = \frac{528 \times Q \text{ (gpm)}}{\text{slope per log cycle}}$$

(Theim method)

Coefficient of Storage (S) - use drawdown in feet in an observation well (piezometer) plotted against time in days since pumping started on semi-logarithmic paper, fit the best straight line or lines, and use the following formula:

$$S = \frac{0.36\ T\ t_o}{r^2}$$

(Jacob method)

Note: Metric equivalents of these formulae are also commonly used.

Permeabilities are calculated in piezometers from rising and/or falling head tests using the appropriate Hvorslev formula of:

$$K = \frac{r_s^2 \ \ln \frac{l}{r_h} \ \ln \frac{h_s}{h_o}}{2\ l\ t}$$

5.0 GROUNDWATER HYDROLOGY continued

5.2 Continued

5.2.1 where:

K = permeability in cm/sec

r_s = radius of standpipe in cm

r_h = Radius of hole in cm

h_s = head at start of test in cm

h_o = head at end of test in cm

l = length of open hole equals length of sand packed hole in cm

t = time to rise or fall in seconds

ln = natural log to base "e".

5.2.2 Changes in Transmissivity

The accompanying graphs show the cones of depression or influence around a well for various values of T when the other parameters are held constant. These graphs are plotted on semi-logarithmic paper where all cones show as straight lines and on arithmetic graphs with curved plots. Reference to Figures 3 and 4 will show that the constant factors are time at 10 days, storage coefficient at 0.015 and a per well discharge of 100 gpm. Curves were drawn using these values and values of T of 3000, 2000, 1000 and 500 gpd/ft.

It will be noted that at a radius beyond 120 meters (400 feet) from the well that there is little significant difference in the cones as T varies from 1000 to 3000 gpd/ft.

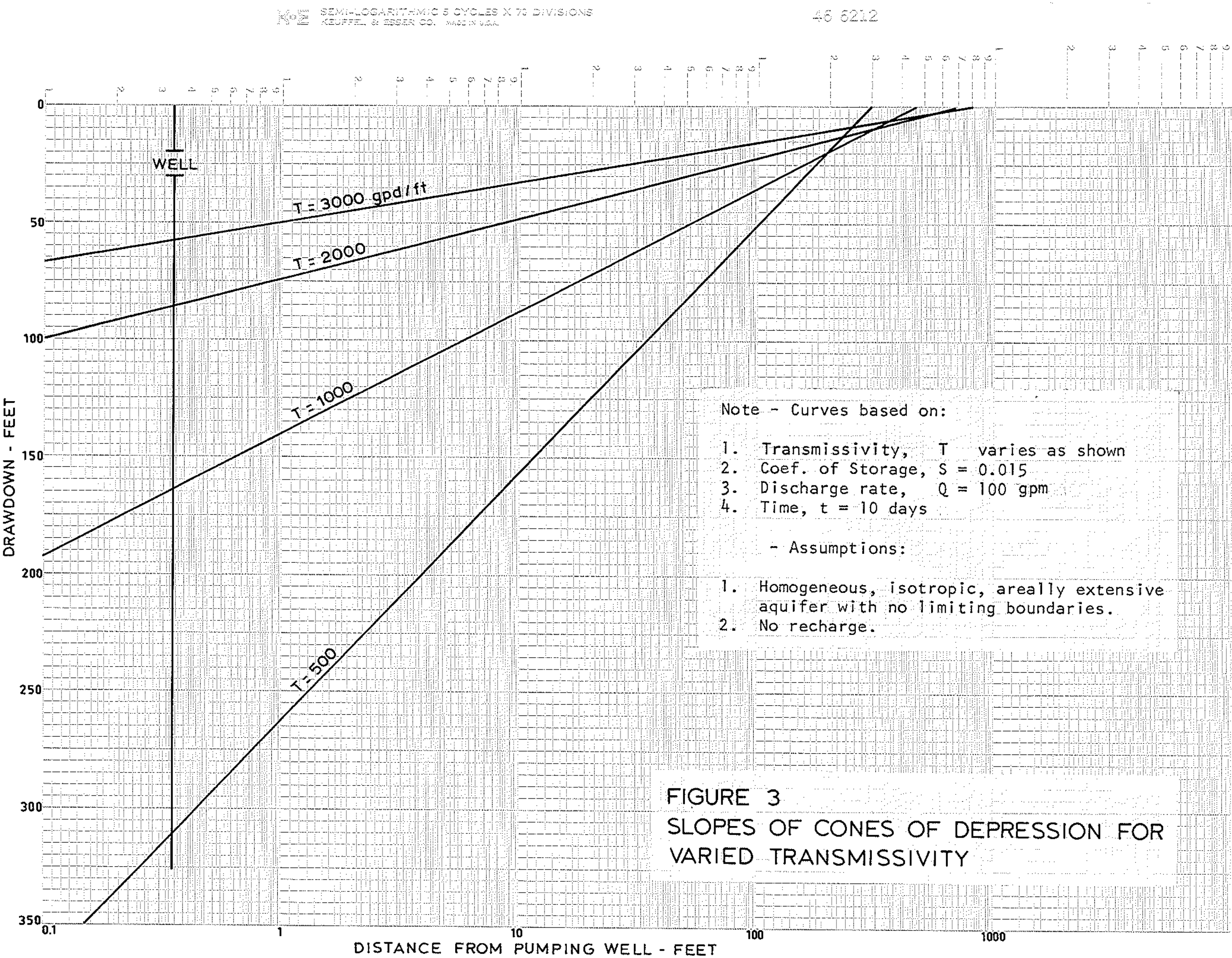
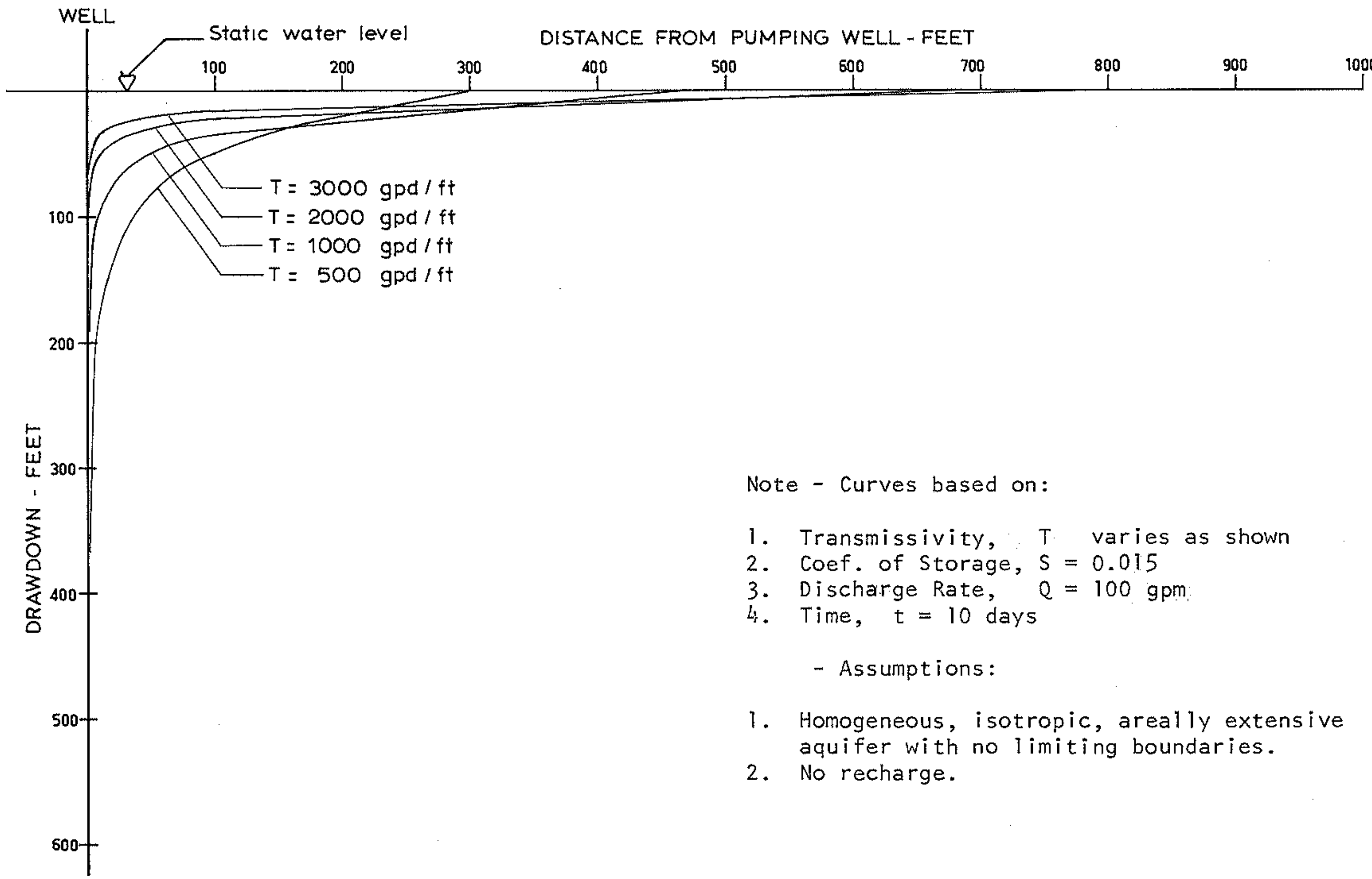


FIGURE 3
SLOPES OF CONES OF DEPRESSION FOR VARIED TRANSMISSIVITY



Note - Curves based on:

1. Transmissivity, T varies as shown
2. Coef. of Storage, S = 0.015
3. Discharge Rate, Q = 100 gpm
4. Time, t = 10 days

- Assumptions:

1. Homogeneous, isotropic, areally extensive aquifer with no limiting boundaries.
2. No recharge.

FIGURE 4
SLOPES OF CONES OF DEPRESSION FOR VARIED TRANSMISSIVITY

5.0 GROUNDWATER HYDROLOGY continued

5.2 Continued

5.2.2 Thus at 120 meters (400 feet) or greater distances from the pumping well a change of T from 1000 to 3000 or by a factor of 3 does not give any significant changes in the lateral extent of the cones of depression. A T of 500 gpd/ft, however, does show a significant difference from the higher values of T with a zero drawdown point at a radius of 90 meters (300 feet) from the well and a much steeper cone.

Changes in T values are significant at the well and within a radius of 30 meters (100 feet) from the well. This can be readily observed on Figures 3 and 4.

5.2.3 <u>Changes in the Coefficient of Storage</u>

Figures 5 and 6 show the changes in the extent of the cones of influence about a pumping well when S varies from 0.01 to 0.0001 or by a factor of 100.

The most obvious characteristic of this set of curves is that they are parallel and that the cone of influence becomes larger and deeper as the S becomes smaller. The difference between the cones for S = 0.015 and for S = 0.01 is only 3 feet. Thus no significant change occurs when S is changed by a factor of 1.5.

When the S is changed by a factor 10 the drawdown changes by 7.5 meters (25 feet).

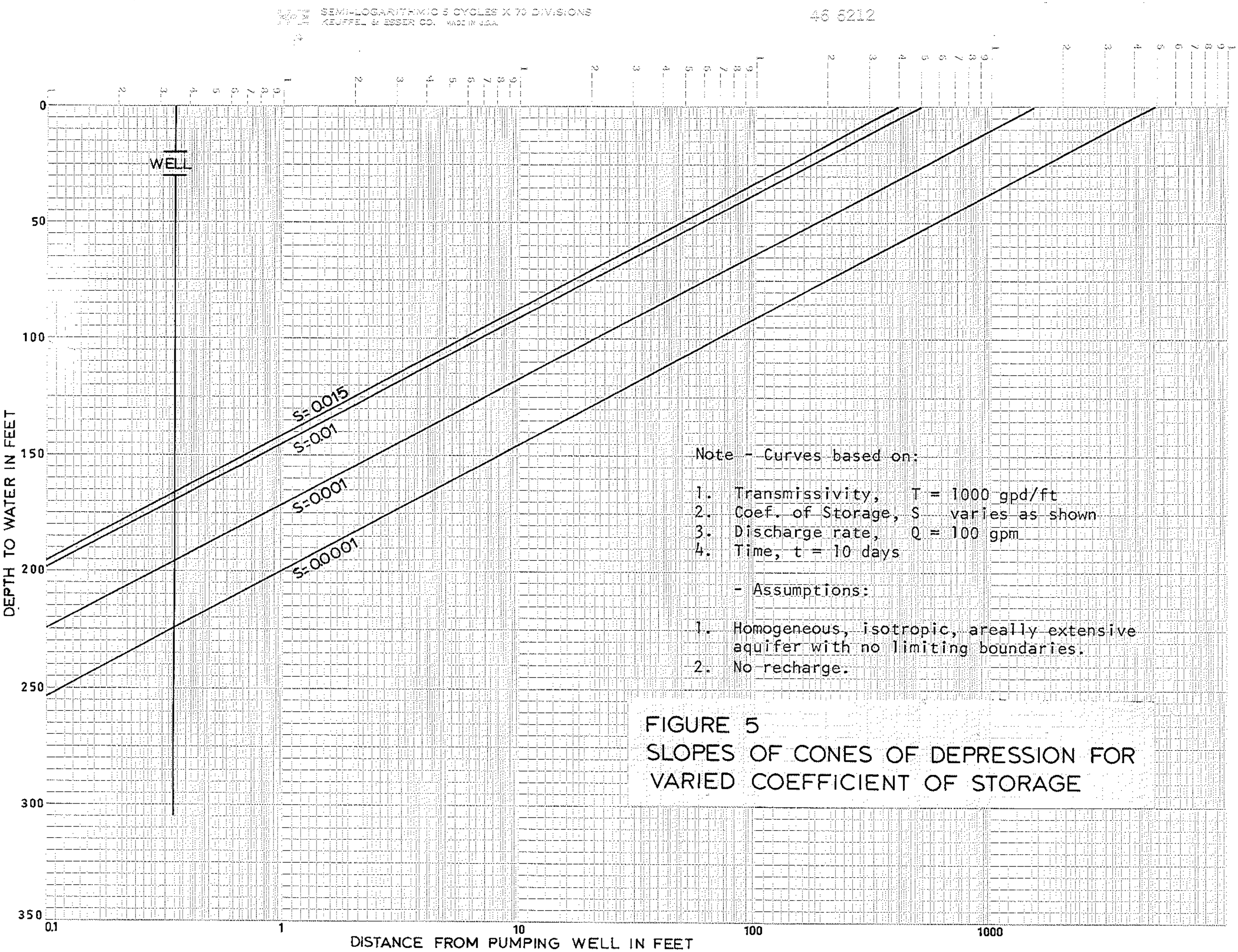
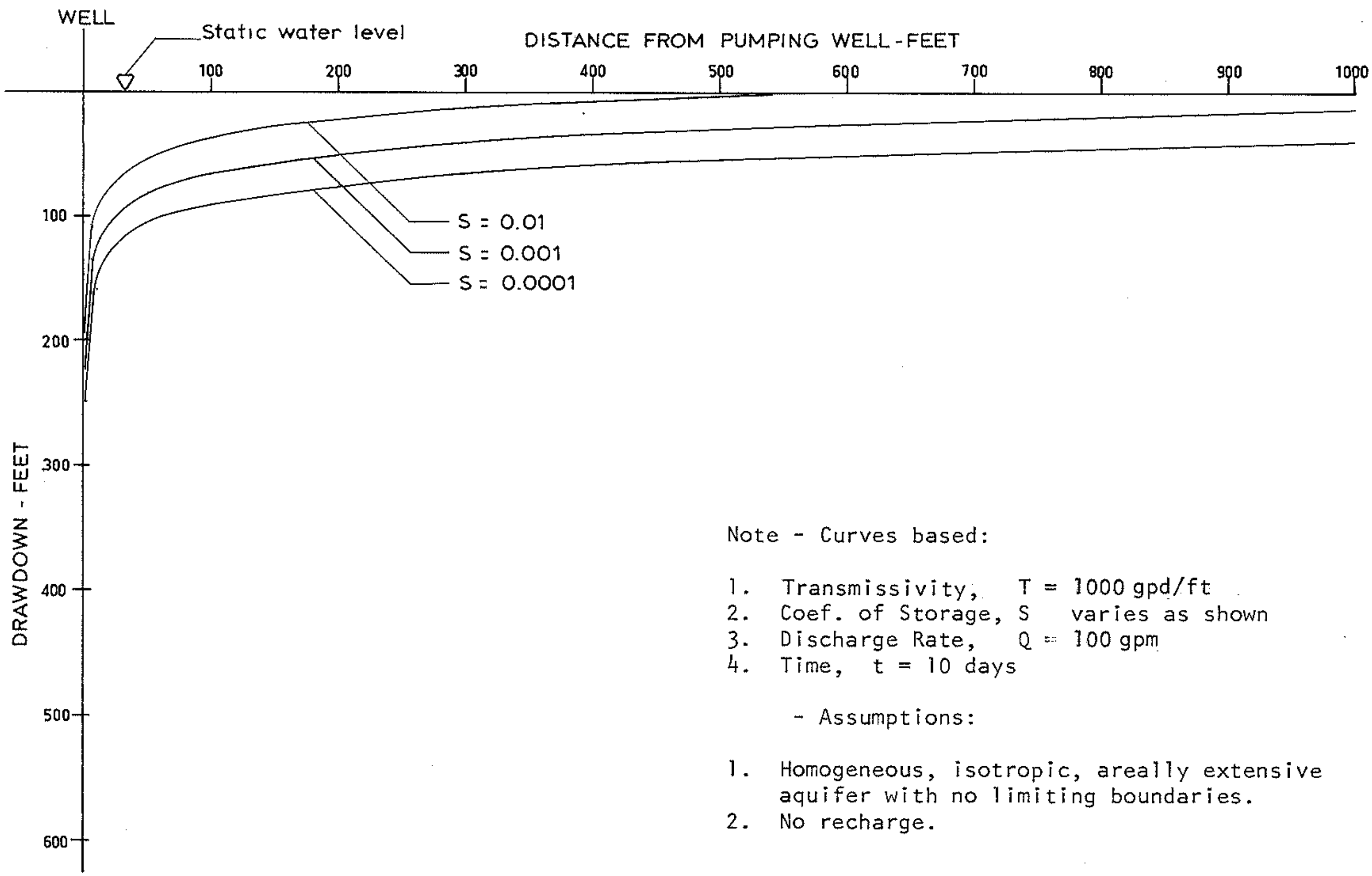


FIGURE 5
SLOPES OF CONES OF DEPRESSION FOR VARIED COEFFICIENT OF STORAGE



Note - Curves based:

1. Transmissivity, T = 1000 gpd/ft
2. Coef. of Storage, S varies as shown
3. Discharge Rate, Q = 100 gpm
4. Time, t = 10 days

- Assumptions:

1. Homogeneous, isotropic, areally extensive aquifer with no limiting boundaries.
2. No recharge.

FIGURE 6
SLOPES OF CONES OF DEPRESSION FOR VARIED COEFFICIENT OF STORAGE

5.0 GROUNDWATER HYDROLOGY continued

5.2 Continued

5.2.3 Although altering the coefficient of storage by a factor of 10 is significant, doubling the coefficient would cause little significant change from a practical point of view in the design of a dewatering system.

5.2.4 Changes in Time

Reference to Figures 7 and 8 will show that as the time factor changes by a factor of 10 from one day to 10 days and from 10 days to 100 days the cones deepen by 7.5 meters (25 feet) and spread outwards but remain parallel to each other.

The hydrodynamics of an open pit dewatering system are such that the majority of drawdown is caused in the first 10 to 15 days of pumping and that as the cone of depression spreads laterally and affects a larger area the rate of drawdown diminishes. This can easily be seen seen in Figure 7 where, using the stated parameters, a drawdown of 50 meters (165 feet) can be achieved in the first 10 days but after 90 additional days (i.e. 100 days total) drawdown has only been increased by an additional 7.5 meters (25 feet). To further complicate this situation, improperly designed dewatering schemes which allow excessive underflow can reach an equilibrium condition of no additional drawdown too quickly and dewatering schedules may not be achieved. Therefore although there may be a very long period of time available to get the water down in pits we believe it prudent to use a design time factor of only 10 days.

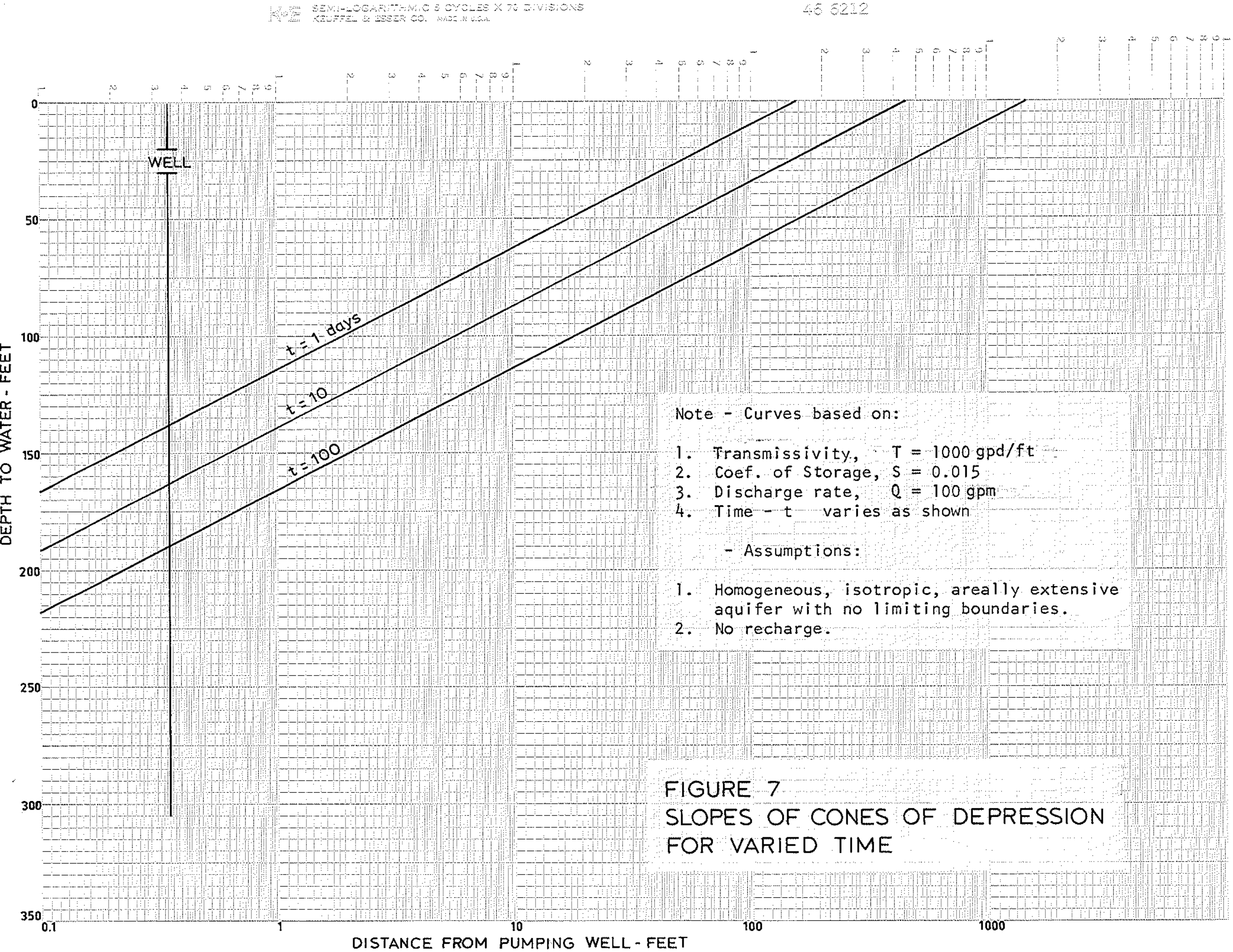
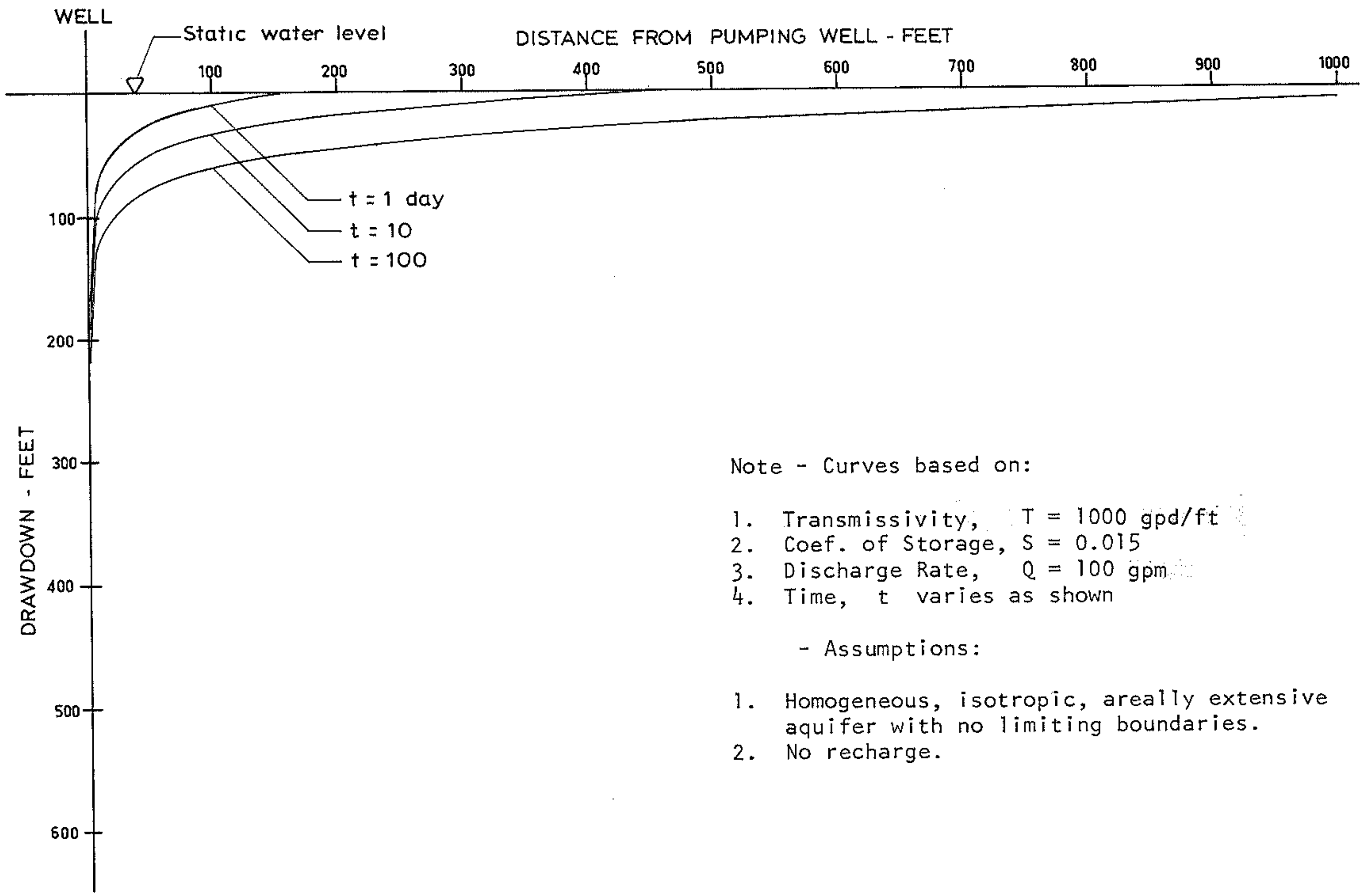


FIGURE 7
SLOPES OF CONES OF DEPRESSION FOR VARIED TIME



Note - Curves based on:

1. Transmissivity, T = 1000 gpd/ft
2. Coef. of Storage, S = 0.015
3. Discharge Rate, Q = 100 gpm
4. Time, t varies as shown

- Assumptions:

1. Homogeneous, isotropic, areally extensive aquifer with no limiting boundaries.
2. No recharge.

FIGURE 8
SLOPES OF CONES OF DEPRESSION FOR VARIED TIME

5.0 GROUNDWATER HYDROLOGY continued

5.2 Continued

5.2.5 Changes in Flow (Discharge of Quantity-Q)

Since drawdown varies directly (in a perfect well or system of perfect wells) with the discharge rate for both individual wells and a system of wells it was not considered necessary to show graphs for varying discharge rates. As the discharge rate increases the cone deepens by rotation around the point of zero drawdown.

5.3 Recharge - Discharge

Experience dictates that 10% of the average annual precipitation will enter the ground and recharge the subsurface groundwater-bearing reservoirs each year beneath an area of subdued relief covered by surficial deposits. In areas of relief where bedrock is at or within one meter (3.28 feet) of ground surface the recharge rate is reduced to 2% of the average annual precipitation.

Using these empirical values, the total groundwater recharge to the area between the Campbell and Oyster Rivers and the sea coast to the Campbell Lakes will be:

Coastal Lowland

- area 7 x 12 = 84 square miles
  = 233 square kilometers

- recharge 60/12 x 0.1 = 0.5 feet
  = 0.15 meters

- gallons per cubic foot = 6.23

therefore recharge will be

84 x 5280 x 5280 x 0.5 x 6.23 = 7300 million gallons per year
= 13,900 gpm
= 1050 l/sec.

5.0 GROUNDWATER HYDROLOGY continued

5.3 Continued

Vancouver Island Ranges

- area 9 x 12 = 108 square miles
  = 300 square kilometers

- recharge 60/12 x .02 = 0.1 feet
  = 0.03 meters

therefore recharge will be

$$108 \times 5280 \times 5280 \times 0.1 \times 6.23 = 1900 \text{ million gallons per year} = 3600 \text{ gpm} = 270 \text{ l/sec.}$$

Thus the total expectable groundwater flow beneath the area of interest is 1320 l/sec (17,500 gpm).

If we assume that the water that recharges the groundwater reservoirs each year flows to the coast with an average gradient of 610 meters (2000 feet) over an average of 27 kilometers (16 miles) then the average permeability of all the sediments and rocks can be calculated as follows:

$$Q = 17{,}500 \times 1440 = 25 \times 10^6 \text{ gpd}$$

$$I = 610/27{,}000 = 0.023$$

$$A = 12 \times 5280 \times 500 = 32 \times 10^6 \text{ square feet}$$

therefore

$$K = 25 \times 10^6 \, (0.023 \times 32 \times 10^6) = 34 \text{ gpd/ft}^2 = 1.9 \times 10^{-3} \text{ cm/sec.}$$

Since this appears to be a reasonable figure for materials that range from 1×10^{-8} to 2×10^{-1} cm/sec, our assumptions are generally correct. (Please see 5.1.1).

6.0 EFFECTS OF MINING

6.1 During Mining

Based upon presently available data, it is difficult to ascertain exact dewatering requirements during mining operations. Although we consider that an extensive system of dewatering wells will not be required to stabilize pit slopes or facilitate mining, it is probable that some dewatering will be required. We envisage that this dewatering will be achieved by sporadically located wells around pit perimeters and by the use of sumps and ditches in a manner that is standard practise in excavations.

Two important areas where wells may be needed are:

a) Major fault and fracture zones cutting through the coal-bearing sediments intersect pit walls or lie close behind pit faces.

b) Glacio-fluvial sands and gravels filling buried channels are close to pit faces or cut into the pits.

The permeability of the fractured coal-bearing sediments is believed to be 1×10^{-4} cm/sec. This permeability will cause the cone of depression to rise sharply away from the pits. Reference to Figure 3 will show that the cone of depression around the pit will not extend more than 150 meters (500 feet) outwards from the pits faces. In all probability it will not extend outwards more than 100 meters (300 feet) along the major fault and fracture zones.

The configuration of the drawndown water surface can be drawn with a fair degree of accuracy after the pit shapes and slopes have been defined and after pumping tests have been completed and analysed during the permit stage.

6.0 EFFECTS OF MINING continued

6.1 Continued

We believe that the lakes and rivers in the mine area are perched on relatively impermeable organic silts and clays. If this is shown to be true (by pump tests during stage 3) then the lowering of the water table-piezometric surface during mining will have minimal effect on surface waters.

Buried channels filled with over 50 meters (165 feet) of glacial drift have been discovered in the south block and east of Middle Quinsam Lake near Iron River. These channels most probably contain sands and gravels similar to the medium to coarse grained sands and gravels reported by Gardner et al (Reference 16) to be present at the south end of the pits. These sands and gravels will have a relatively high permeability of 2×10^{-1} cm/sec. Reference to Figure 3 will show that the cone of depression will extend outwards a distance of almost 300 meters (1000 feet). The configuration of the channels in the mine area must known in detail at some time prior to mining so that dewatering systems can be designed and activated before the pits are opened. Wells located in these sand and gravel filled channels could produce in excess of 100 litres per second (1300 gallons per minute) on startup with a gradual decrease in productivity as dewatering takes place. The ultimate yields can only be judged after the configuration of the channels is known.

6.2 After Mining

It is assumed that the pits will be filled, shaped, covered with soil, and planted with trees and grasses when abandoned. This type of abandonment will essentially return the area to its natural condition. Thus within

6.0 EFFECTS OF MINING continued

6.2 Continued

a year after total abandonment the regional groundwater conditions should return to the natural conditions. Monitoring of piezometers or observation wells located outside of pit limit should continue during this stage to describe any local changes in groundwater quality or movement.

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