FEASIBILITY OF ARTIFICIAL RECHARGE OF A SMALL GROUND WATER BASIN BY UTILIZING SEASONAL RUNOFF FROM INTERMITTENT STREAMS

A preliminary study of artificial recharge of ground water in Moscow basin, Latah County, Idaho

by

Robert W. Jones
Department of Geology and Geography
University of Idaho

Sylvia H. Ross
Idaho Bureau of Mines and Geology

Roy E. Williams
Department of Geology and Geography
University of Idaho

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R. W. Jones, S. H. Ross, and R. E. Williams

INTRODUCTION

The City of Moscow and the University of Idaho are the principal users of ground water in Moscow basin. Water is obtained from artesian aquifers in the basalt flows and interbedded sediments of the Columbia River Group.

From 1896 to the 1960's, all water was obtained from an artesian aquifer that is at a depth of about 250 feet. Water levels in the wells declined steadily over the years; the total decline at the city pumping plant was about 100 feet by the 1960's. The water in the aquifer is of poor quality becasue of high concentrations of iron.

City and University authorities have been studying the problems of Moscow basin water supply for years. The nearest streams with large sustained discharge are 20 miles away. Exploration for other ground-water supplies led to the discovery of good quality water in productive aquifers at depths of 700 feet and 1300 feet.

During the 1960's, the City and the University shifted nearly all pumpage to the deeper aquifers. Water levels in the upper aquifer have been rising steadily since heavy pumping ceased and now are about 15 feet higher than the low levels of a few years ago.

The properties of the deeper aquifers are not yet known and the amount of water that they will yield over long periods of time is uncertain. However, they may be similar to the upper aquifer which does not seem capable of producing the amount of water needed. Although no problems are yet apparent with the deeper aquifers, strong possibility exists that they also will show a long-term decline of water levels, indicating depletion of the supply of ground water.

Projected future demands suggest that twice the amount of water now being pumped will be needed by the year 2000. We are not certain that this demand can be met by the naturally-available ground water.

Although one of the most obvious answers is to import surface water from outside of the basin, the cost would be an enormous burden on the present economy of the area. The nearest dependable streams, 20 miles distant, are at elevations that are 2100 to 2300 feet lower than the level of Moscow. In addition to the construction cost of 27 miles of pipeline, operation costs would be high because of the high pumping lift. We believe that this project would cost about 7 million dollars.

One proposed reservoir site that would permit gravity flow is 35 airline miles from Moscow and would require about 40 miles of pipeline. The tentative price tag is about 25 million dollars.

Our preliminary study, utilizing mostly estimated data, indicates that artificial recharge of ground water by utilizing seasonal runoff from intermittent streams in and near Moscow basin is a feasible and cheaper alternative to long-distance importation of surface water. The construction would be in three stages spaced out over at least 30 years.

The first stage would begin in the next few years. It would cost about 2 million dollars and probably would provide about 480 million gallons of additional water in a normal year from the South Fork Palouse River. Assuming that the naturally-available ground water will provide about 500 million gallons annually, the first stage would probably meet demands until about 1980.

The second stage would be constructed about 1980. It would cost about 2 million dollars and probably would provide another 480 million gallons of water from Little Bear Creek. The addition of the second stage probably would meet demands past the year 2000.

After the year 2000, the effluent of the Moscow waste-water treatment plant would be utilized. By then, the annual discharge of the plant would be around 1 billion gallons. As of the year 2000, the water resources of Moscow basin would be:

Naturally-available ground water	0.50 billion gallons
Artificial recharge from streams	0.96 billion gallons
Treated waste water	1.00 billion gallons
Total available water	2.46 billion gallons
Anticipated demand	1.36 billion gallons
Surplus	1.1 billion gallons

Acknowledgements

The concept of artificial recharge in the Moscow-Pullman area is not original with us. Stevens (1960, p. 347) discusses it briefly and Foxworthy (1963, p. 36-41), in more detail. C. C. Warnick of the University of Idaho Water Resources Research Institute has encouraged investigation of the idea. Several years ago, J. W. Crosby III of the Alderbrook Hydraulic Laboratory at Washington State University outlined a proposed program of research on artificial recharge in the Moscow-Pullman area. Although his proposal was not put into effect, we did follow some of the same lines of investigation in our studies.

Professor Frank Junk of the Civil Engineering Department of the University of Idaho aided in computation of the estimates for the construction costs.

Much of the data used in the study were furnished by the City of Moscow (R. O. Day, Municipal Engineer) and the University of Idaho Physical Plant Division (George Gagon, Director). Records of water level measurements in observation wells were furnished by the U.S. Geological Survey. The basic data were published in Ross (1965) and Jones and Ross (1968).

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Location and Extent of Area

The Moscow ground-water basin is in west-central Latah County, in northern Idaho (Fig. 1). The amphitheater-like basin has an area of about 58 square miles. The boundaries are well defined by stream divides on the north, east, and south. The western boundary has been set arbitrarily at the Washington-Idaho state line for this report, although Moscow basin actually is part of the larger Moscow-Pullman basin of Idaho and Washington. The poorly-defined southwest and northwest boundaries have been selected to include only those tributary streams that join the main streams within Idaho.

The climate of the area is transitional between semi-arid and subhumid. Winters are moderately cold and summers are warm. Mean annual temperature is about 48°F.

Precipitation averages slightly more than 22 inches a year at Moscow, where the elevation is about 2600 feet above sea level. It has been estimated that precipitation on the higher mountains on the northeast of the basin may be perhaps twice the average precipitation at Moscow. Almost three-fourths of the precipitation falls from October through April.

AREA GEOLOGY

Moscow basin consists of a rolling surface of low hills at the eastern margin of the Palouse Hills section of the Columbia Intermontane province and of mountains at the western margin of the Northern Rocky Mountain province. The mountains (Fig. 1) are underlain by granitic and metamorphic rocks of Cretaceous (?) and Precambrian age respectively (Tullis, 1944, p. 143-174). The western part of the Basin (Palouse Hills section) is underlain by a sequence of basalt and interbedded sedimentary material as much as 1400 feet thick. The basalt, part of the Columbia River Group, filled deep existing canyons that drained the mountains to the north and east. The interbedded sediments, which in the Moscow area make up almost 50 percent of the total sequence, are primarily clays, silts, and fine-grained sands; most resemble lake deposits, although some stream deposits are present.

The Columbia River Group is overlain by reddish-brown loess (wind-blown silt) of the Palouse Formation.

AREA HYDROLOGY

Essentially all water in the Moscow basin is supplied as precipitation; therefore, a quantitative statement of hydrologic equilibrium may be stated in a simple form: ground-water recharge is equal to precipitation minus evapotranspiration minus surface runoff. Although we have some data on precipitation and runoff, too few stations are in operation to provide really adequate information. We have almost no data on evapotranspiration.

Precipitation

Precipitation at Moscow is approximately 22 inches annually. However, because of increased elevation, average precipitation over the entire basin probably approximates 1½ times the precipitation at Moscow (Sokol, 1966, p. 7). A relatively large amount of this precipitation falls as snow during the winter months. Although the snow pack at lower elevations melts several times each winter, much of the snow at higher elevations remains through the winter. During the spring, snow melts at progressively higher eleveations, so that much snow at intermediate elevations is melting when snow at higher elevations remains on the ground.

Evapotranspiration

Although no measurements of evapotranspiration have been made within Moscow basin, extrapolation of information from nearby areas gives estimates that range from 50 to 82 percent of precipitation (Stevens, 1960, p. 342; Sokol, 1966, p. 7-8).

Surface Runoff

For the entire Moscow-Pullman basin, stream flow averages about 15 percent of precipitation; however, calculations are based on extrapolations of short-term stream gaging. At higher elevations, in small subbasins underlain by granitic and metamorphic rocks, a larger percentage of the precipitation occurs as runoff. At higher elevations, streams respond mainly to snow melt; at lower elevations, heavy rainfall is a more important source of stream flow.

Ground Water

Ground water occurs in all rock types in Moscow basin: granitic and metamorphic rocks, loess and recent stream alluvium, and the basalts and interbedded sediments of the Columbia River Group. However, confined (artesian) water in large amounts occurs only in crevices, brecciated zones, and vesicles in the basalt and in the intercalated sand layers of the Columbia River Group.

HYDROSTRATIGRAPHIC UNITS

The most common surface materials are the loess deposits of the Palouse Formation. Alluvium and lacustrine deposits also are present; some are younger and some are older than the Palouse Formation. Because these units are not important aquifers for public supply wells, we have lumped them together as the surficial aquifers (Fig. 2).

The Columbia River Group is divided into three lithologic and hydrologic zones. Each zone consists of an upper subzone of basalt flows and a lower subzone of sedimentary interbeds. The sedimentary interbeds pinch out within a short distance to the west.

Each lithologic zone contains one or more artesian aquifers which yield water to public supply wells. A number of public supply wells formerly used the upper artesian zone, a few industrial and irrigation wells and numerous domestic wells still do. The most productive portions of the upper artesian zone are near the base of the upper basalt and at the upper part of the upper interbed. One well produces from the middle artesian zone; although it was drilled to the lower artesian zone, it did not produce from there. However, two wells do produce from the lower artesian zone. The basement complex does not yield water to wells.

WATER LEVEL TRENDS IN THE UPPER ARTESIAN AQUIFER

Very little data are available on water levels and water pumped prior to 1948 when the City of Moscow began to keep records of daily depth measurements and daily readings of meters on the pumps. The University of Idaho began to keep similar records in 1956. The U.S. Geological Survey has taken periodic water level measurements since 1937 in an observation well (7dd1) in the upper artesian zone.

Water levels and pumpage for the upper artesian aquifer since 1896 are shown on Figure 3. Prior to 1960, the pumpage shown is the total pumpage for public supply wells in the basin; after 1960, part or all of the public supplies was obtained from the deeper aquifers.

Pumpage

During the period 1955-1966, the lowest annual pumpage for the public supply wells in Moscow basin was 442 million gallons in 1956 and the highest annual pumpage was 752 million gallons in 1963; the average was 620 million gallons.

The main cause of pumpage fluctuations seems to be precipitation fluctuations, especially during the summer lawn-watering season. The highest annual pumpage, 752 million gallons in 1963, was followed by a low pumpage of only 557 million gallons in 1964 when the summer precipitation was unusually high. Nevertheless, the overall pumpage is increasing; the 1961-1966 average was 675 million gallons compared to the 1955-1959 average of 570 million gallons.

Pumpage from 1940 through 1947 is estimated from data on sales of water by the City of Moscow. After making allowances for leakage and other losses, we obtained good agreement between sales of water and water pumped according to pump meters after 1948. Therefore, the 1940-1947 estimated data probably are accurate.

Because population was fairly stable, the average of the 1940-1945 data --- 310 million gallons annually --- is projected backwards as the average pumpage to 1925. Pumping prior to 1925 is believed to have been much lower because City well 2, the first well with a large yield, was drilled in 1925. Laney, Kirkham and Piper (1923, p. 11) present some data on 1923 water usage. We have recomputed their data and have obtained a probable annual pumpage of 152 million gallons which has been taken to represent the pumpage for the period 1896-1924.

Currently, the University of Idaho does not pump from the upper artesian aquifer and the City of Moscow pumps from it only during peak demand periods in the summer.

Water Level Trends

Water levels at the City pumping plant declined at a fairly steady rate of about 1.3 feet a year from 1896 to about 1948; thereafter, the rate was about 2.8 feet per year until 1960. Increased usage following major improvements to the distribution system along with increased per capita usage of water and increased population contributed to the increased decline after 1948.

During late 1960 and part of 1961, the City did not pump any water from the upper artesian aquifer. No measurements were taken at the City pumping plant during this period, but the water levels in the observation well (7dd1) rose nearly 4 feet. The water levels in the observation well declined again when the city resumed pumping from the upper artesian aquifer in 1961.

By 1965, the University had ceased pumping the upper artesian aquifer and the City had restricted pumping to peak demand periods. Water levels have been rising ever since; the water level in the observation well was at elevation 2495.7 on April 1, 1968.

Predicted Future Pumpage

Our projections of pumpage suggest that the average annual pumpage will be about 800 million gallons in 1975 and that peak-year demands may be about 900 million gallons. A consulting report prepared for the City of Moscow projected demands to the year 2000. With our estimates for the University demand added, the predictions are:

Year	City of Moscow	University of Idaho	Total Millions of Gallons
1970	620	220	840
1980	800	290	1090
1990	910	330	1240
2000	1000	360	1360

Effects of Predicted Pumpage

We have not as yet studied what the effects of the predicted pumpage will be on the deeper artesian aquifers. The record of operation of the upper artesian aquifer suggests that it can be depended upon to yield only a few hundred million gallons a year over long periods of time. The deeper aquifers may have similar properties to the upper artesian aquifer. If they do, they may not be able to yield the required amounts of water.

We believe that the three artesian aquifers together would yield about 500 million gallons annually without serious danger of depletion. Thus, an additional 500 million gallons would be needed by 1980 and yet another 400 million gallons would be needed by 2000.

PIEZOMETRIC SURFACE

According to Newcomb (1959, p. 7), aquifers in the Columbia River Group are:

> . . . separate tabular zones, each of which is interrupted in many places but nevertheless is of rather widespread lateral extent. In some places cubical or "brickbat" and other types of fractured basalt allow hydraulic continuity between nearby permeable zones. Also, locally, water in some aquifers is isolated vertically by impermeable massive parts of lava flows.

In Moscow basin, each of the artesian zones contains one or more artesian aquifers which seem to resemble those described in Newcomb. Direct vertical hydraulic connection between the zones seems to be poor; each deeper zone has a piezometric surface about 100 feet lower in elevation than the piezometric surface of the next higher aquifer. In 1966, the piezometric surfaces were:

Artesian Aquifer	Approximate Elevation of Piezometric Surface (ft. above msl)
Upper	2500
Middle	2400
Lower	2300

Although these differences indicate poor vertical hydraulic connection, they do not prove that downward movement of water does not take place. We suggest that the 100 feet of difference in potential may be adequate to cause considerable downward movement of water through leaky confining beds.

We believe that the upper artesian zone includes one principal aquifer of considerable lateral extent which has a mappable piezometric surface. The zone also includes one or more less extensive aquifers that have markedly different heads compared to the main aquifer. Our interpretation of the piezometric surface of the main aquifer of the upper artesian zone as of 1966 is shown in Figure 4. Our interpretation is that the surface shows a residual cone of depression. The map differs in some respects from previously published maps (Laney, Kirkham, and Piper, 1923; Ross, 1965; Chang-Lu, 1967).

We show a closed cone of depression along the South Fork Palouse River in the southeastern extension of Moscow basin; this is the result of heavy pumpage for irrigation and industrial purposes. The closure is drawn on the basis of water levels in several wells drilled in recent years in the vicinity of the piezometric divide. This interpretation suggests that no recharge enters the upper artesian aquifer in the main part of Moscow basin from the South Fork Palouse River valley.

Our data require that we show the center of the cone of depression as displaced to the north of the main pumping center at the City pumping plant. The reason for the displacement is not known.

The closure of the contours to the northwest of the main basin is based on the assumption of a closed residual cone of depression. Chang-Lu (1967, p. 73) presents another interpretation that the shape of the piezometric surface of this part of the basin is controlled by a buried valley in the surface of the upper interbed. The valley is filled with basalt that has high permeability and forms a ground water conduit. The high permeability permits the water to move at lower heads; therefore, a trough in the piezometric surface exists over the buried valley and the contours do not close to the west. Very few wells are present to the west and the data permit either interpretation. For the purposes of artificial recharge, the closed residual cone of depression presents the more pessimistic set of conditions; therefore we decided to work with the residual cone.

FLOW SYSTEMS

To demonstrate the effects on the upper artesian aquifer of pumping and of recharging, we have constructed flow nets along line A-A' of Figure 4. These flow nets were derived from studies of analogs in which boundary conditions approximate those in Moscow basin. We do not have sufficient geohydrologic information to construct a precise analog of Moscow basin; therefore, the nets are schematic.

Figure 5 shows the schematic flow of ground water to a cone of depression in a field of lateral flow---a field of flow in which the cone of depression has no effect on the ground water potential at the boundaries. Therefore, as far as the well is concerned, the field has no boundaries. The values of coefficient of transmissibility and coefficient of storage that we are using for Moscow basin are such that 8 hours of pumping one of the existing public supply wells at its usual rate would result in a cone of depression that does not reach the boundaries of the field. Therefore, Figure 5 is a fair approximation of the day to day pumping operation of the upper artesian aquifer. Reversing the operation of the net by making the well a recharge well would result in a cone of impression that would not reach the aquifer boundary in 8 hours of operation.

However, using the same aquifer properties, continuous pumping--- or recharge --- for periods much longer than 8 hours results in cones of influence that reach the boundaries of the aquifer. Figure 6 shows the schematic flow system for these conditions with a pumping well. The well is in a field of radial flow where the cone of depression intersects the boundaries. This flow system is important both to the pumping and to the artificial recharge of Moscow basin.

We are proposing a plan for artificial recharge that will ordinarily operate 24 hours a day for about 100 days a year. Therefore, the cone of impression will reach the boundaries of the aquifer and the potential will build up at the boundaries. In making geohydrologic calculations on such a system, it is necessary to take into account the effects of the boundaries; such a system is handled by the method of image wells.

ARTIFICIAL RECHARGE

In order for artificial recharge to be feasible, a source of water must be available that is large enough and dependable enough to justify the investment in the construction of the treatment plant and recharge facilities. The recharge water must be chemically compatible with the ground waters in the aquifer. If injection through wells is to be used, the recharge water must be free of silt, bacteria, and algae, or must be capable of being treated to remove these undesirable constituents. A site for recharge must be available. The entire program must be feasible economically as well as technically.

We believe that conditions in Moscow basin make artificial recharge technically feasible. We believe that the lower costs of artificial recharge compared to long-distance importation of water also make artificial recharge economically feasible in Moscow basin.

Sources of Water

Several intermittent streams originate on the south flanks of the mountains north and northeast of Moscow basin (Fig. 1). These streams have very low flows except during the spring months.

The eastermost of the streams in Moscow basin is the South Fork Palouse River; outside of Moscow basin, the next stream to the east of South Fork Palouse River is Little Bear Creek. Each of these two streams may yield about 480 million gallons for artificial recharge during a normal year; a total of 960 million gallons annually may be available.

The Moscow waste-water treatment plant now treats about 300 million gallons annually and will treat more as the population of the City and the enrollment in the University increase. By the year 2000, as much as 1000 million gallons may be treated annually.

Utilization of all of these resources would yield about 1260 million gallons in a normal year at present rates, and more in the future.

South Fork Palouse River

South Fork Palouse River is the only stream in Moscow basin that has a spring runoff large enough and dependable enough to be used for artificial recharge. It flows through Robinson Lake, a small recreational reservoir which is about 4 air-line miles ENE of Moscow (Fig. 1). The drainage basin above Robinson Lake is about 6 square miles in area.

For a number of years, the University of Idaho has operated a gaging station on Crumarine Creek, a principal tributary of the South Fork Palouse. The gaging station is about 1½ miles upstream of Robinson Lake; the drainage basin above the gage is about 2 square miles in area. Seven years of good records are available during the period 1956-1964. The records show that for most years, spring runoff begins in February, continues through March, April, and May, and part way into June. Flows of greater than 500 gpm (gallons per minute) seldom occur later than mid-June. In general, the runoff is over before the summertime heavy pumping demand begins in Moscow. Thus, the runoff currently is not available when needed.

Our analysis of the Crumarine Creek stream gage records shows:

Flow (gpm)	Number of Days	
	6 years in 7	3-4 years in 7
More than 2000	40	50
1500 - 2000	20	10
1000 - 1500	10	30
500 - 1000	20	30

If we use only the water that passes the Crumarine Creek gaging station and if we install a system that will recharge a maximum of 2000 gpm and operate the system at any time that as much as 500 gpm is available, we will be able to recharge at least 182 million gallons during 90 days of operation in 6 years out of 7. We will be able to recharge 224 million gallons during 100 days of operation during 3 or 4 years in 7. However, the seventh year for which we have record was very dry; flow at the gaging station exceeded 500 gpm only on 50 days and seldom exceeded 1000 gpm---the water available for recharge would have been only 35 million gallons.

By building one or more small reservoirs, the stream flow could be regulated so as to store water in excess of that needed for the immediate operation of the artificial recharge plant. We will be able to obtain an additional 40 million gallons for delayed recharge during 5 years in 7 and another 15 million gallons 3 years in 7. During 1 year of record---1956---over 100 million gallons additional water would have been available.

For purposes of computation, we suggest that during a normal year, Crumarine will yield 200 million gallons on a run-of-river basis and a total of 240 million gallons if the flow is regulated. More water would be available in some years and less in others. However, annual variations in stream flow are less important to artificial recharge systems than to systems that rely on surface stroage. In years that water is unusually abundant, the excess can be recharged and left in the ground to be pumped out during the years that water is less abundant.

If we divert water at Robinson Lake, the area of the drainage basin is about three times as great as the area of the Crumarine Creek drainage basin above the stream gage. The amount of water available probably is not three times as large, but may very well be twice as large.

Assuming that flow at Robinson Lake is twice as large, our extrapolation of the Crumarine Creek data to Robinson Lake is:

	Number of Days	
Flow (gpm)	6 years in 7	3-4 years in 7
More than 4000	40	50
3000 - 4000	20	10
2000 - 3000	10	30
1000 - 2000		

Thus a 2000 gpm run-of-the-river recharge system operating at a 1000 gpm minimum would be able to recharge 232 million gallons during 90 days of operation in 6 years out of 7. We would be able to recharge 300 million gallons during 120 days of operation in 3 or 4 years out of 7.

If the artificial recharge plant capacity is increased to 4000 gpm with a 1000 gpm minimum, the Robinson Lake diversion would furnish 375 million gallons in 90 days of operation during 6 years out of 7 and 460 million gallons during 120 days of operation in 3 or 4 years out of 7.

Small reservoirs used for temporary storage and to regulate flow might add an additional 80 to 100 million gallons annually. During a normal year, the South Fork Palouse River at Robinson Lake probably will yield about 400 million gallons on a run-of-river basis and 480 million gallons if the flow is regulated.

Little Bear Creek

We have no data on flow of Little Bear Creek. Depending upon the location of the intake, the drainage basin utilized would be between 8 and 12 square miles in area. We assume that it has about the same characteristics as South Fork Palouse River and assume that it will also yield 400 million gallons annually on a run-of-river basis and 480 million gallons if the flow is regulated. Because the drainage basin is larger, Little Bear Creek might yield more water than South Fork Palouse River.

Moscow Waste-Water Treatment Plant

The most reliable, year-around surface flow of water in Moscow basin comes from the City Waste-Water Treatment Plant. The existing installation provides a high grade effluent from secondary treatment. Addition of tertiary treatment would bring the effluent up to potable standards. According to Mr. Orrin Crooks, Superintendent (oral communication), the average discharge of the plant is now about 900,000 gallons a day and the range of discharge is between 800,000 gallons and 1,800,000 gallons a day. The annual discharge is about 300 million gallons.

The effluent is not now utilized by Moscow, but is discharged into Paradise Creek and flows towards Pullman. This is a water resource that can be utilized; it is in fact, the only water resource that will increase in volume as the population of Moscow basin increases. By the year 2000, the discharge probably will be 1 billion gallons annually; it should be utilized.

Artificial Recharge by Water Spreading

An artesian aquifer can be recharged artificially at it natural recharge area by flooding the surface or by flooding pits or galleries. However, water spreading along the edges of the basalt in Moscow basin does not seem practical because of quality of water problems, unfavorable geology, unfavorable distribution of centers of pumping, and high cost of land.

The high iron content that has long been a serious problem in water from the upper artesian aquifer seems to come from a body of high-iron water lying between South Fork Palouse River and Paradise Creek (Fig. 1). The iron seems to be related to the origin of the high-alumina clays on the partly-buried ridge of bedrock between the two streams. Recharge by spreading over the body of high iron water would force the high iron waters in the direction of the pumping centers, thus aggravating a problem that is already sufficiently annoying.

The geology is unfavorable along the edges of the basalt. Low-permeability clays overlay the basalt and would interfere with downward movement of water.

Artificial recharge in the easterly extension of Moscow basin along South Fork Palouse River would principally benefit the users in that area rather than the City and the campus of the University. Only water that moves past the industrial and irrigation wells would reach the main Moscow basin.

The land along the edge of the basalt is valuable farm land that is slowly being taken over by urbanization. A change of land use to accommodate large water spreading areas would be expensive. As local taxpayers, we do not wish to see any more land in tax-free status in the Moscow area.

Artificial Recharge Through Wells

Recharge through wells seems to be practical for Moscow basin. Initially, some of the existing wells could be used for recharge during the spring runoff season, then the same wells could be used as supply wells during the peak demand season. Later on, it may be necessary to drill new wells.

Recharge of the upper artesian aquifer through wells at the existing pumping centers (Fig. 1) has the advantage that the potential buildup would be directed away from the pumping centers, thus driving the high-iron waters away. We believe that if we recharge iron-free water, we will recover iron-free water during the first part of the pumping season. During the latter part of the season, we would again be using the high-iron, natural ground water. However, because a water treatment plant is a necessary part of the artificial recharge operation, we would be able to upgrade the high iron waters at relatively small additional cost.

Disadvantages of well injection are the need to install new pipeline in a heavily urbanized area and uncertainty as to the life of the wells. The airline distance from the proposed water treatment plant to the City pumping plant is about 3000 feet; presumably, at least 4000 feet of pipeline would be necessary.

Experience elsewhere (Todd, 1959, p. 262) indicates that wells used for artificial recharge may eventually clog up beyond the point that they can be redeveloped. Using the same wells for supply as for recharge will lessen the effects of clogging because the wells will redevelop during the pumping season.

At this time, we do not know what the life would be of a recharge well in Moscow basin. The life of some of the supply wells has been unusually long; in spite of the high iron content. Yields of City well 2 and City well 3 are not notably different today than they were when drilled about 40 years ago. On the other hand, the casing failed in University well 2 in about 12 years; University well 2 has been recased and is in operating condition on standby basis.

Proper management of the quality of the recharge water will help to extend the life of the recharge wells. However, the system should be planned so that future wells can be installed in reasonable proximity of the pipeline that delivers the recharge water.

Another factor to be taken into account is a proposal to move the center of pumping for the upper artesian aquifer to the western edge of Moscow basin. The western pumping center would have a larger natural recharge area. It would also be down-gradient from the recharge center and thus would be in a better position to intercept the artificial recharge.

Quality of Water

Success of artificial recharge depends in part on the quality of water used. Physical, organic, and chemical factors must be taken into account.

The most important physical factor is silt. Todd (1959, p. 265) has calculated that 700 mg (milligrams) of silt in a liter of water would deliver 11 tons of silt to a recharge well during a single recharge season. We lack systematic data on silt in South Fork Palouse River; the few data available range from 12 to 1000 mg per liter. Obviously, silt will need to be removed by a water treatment plant.

We have little control over temperature and dissolved air. During the early part of the recharge season, the recharge water temperature will be only slightly above freezing. This water will be relatively viscous and recharge rate will be relatively low. Later in the season, recharge water temperatures will be higher and rates of recharge will be relatively higher. Water temperatures in the upper artesian aquifer are about 55°F.

Dissolved air carried into the aquifer by recharge water may reduce permeability. Other than designing the system for minimum turbulence in the presence of air, little can be done about dissolved air.

The organic factors are bacteria and algae; both are slime producers that can reduce permeability. They can be controlled by chlorination of the recharge water (Todd, 1959, p. 263).

No great problems in chemical compatibility are anticipated. The few analyses available for the South Fork Palouse River indicate that the river water is not significantly different from the water in the upper artesian aquifer. The river water has about half as much total dissolved solids. Cations are present in about the same proportions in both waters, thus no base exchange problems seem likely. Chloride is about three times more abundant in the river water, but no problem should arise from this condition.

Treatment of the Water

In order to use river water for artificial recharge, it will need to be treated to remove silt and to control organic agencies. We assume that the treatment will be sufficient to bring the water up to potable standards.

Optimum location, design, and operation of the treatment plant require further study and are beyond the scope of this paper. However, in order to have some idea of construction costs, we will suggest one plan but admit it may not be the most desirable.

We propose that most of the silt can be removed by settling basins and rapid sand filters that are located near the site where water is diverted from the streams. Final treatment by flocculation probably will be necessary; we suggest a flocculation plant on a tract of city land near the north edge of Moscow (Fig. 1). We presume that the flocculation plant could be designed that it also could be used for the removal of iron. We anticipate that iron removal would be needed in the latter part of the pumping season when the natural high-iron ground water of the upper artesian aquifer would be pumped.

Available Wells

Two of the wells at the City pumping plant that are in the upper artesian aquifer should be suitable for artificial recharge. City well 2 is 240 feet deep, 15 inches in diameter, and is normally pumped at 1000 gpm with about 20 feet of drawdown. City well 3 is 245 feet deep, 18 inches in diameter, and is normally pumped 1350 gpm with about 10 feet of drawdown. Allowing for some loss of permeability caused by dissolved air, we believe that the two wells will accept recharge at a combined rate of 2000 gpm. It is possible that City well 3 can accept the entire 2000 gpm.

We are assuming that recharge can be accomplished by essentially gravity flow at the recharge well. Head differential---and recharge rate---might be increased by forcing the water underground with pumps.

MATHEMATICAL MODEL STUDY OF ARTIFICIAL RECHARGE OF THE UPPER ARTESIAN AQUIFER

As of 1966, the residual drawdown at the City pumping plant was about 100 feet. As a first approximation, the 100 feet of residual drawdown can be considered to represent space in the aquifer that once stored water and is at least in part available to store water again. However, the entire space cannot be used because recharging creates a cone of impression at the well; the cone of impression is more or less a mirror image of the cone of depression that would be created by pumping the well at the same rate as the rate of recharge. City well 3 has a drawdown of about 10 feet at a pumping rate of 1350 gpm; presumably it would build up a cone of impression about 10 feet high when recharged at the same rate. The apex of the cone would gradually rise as water entered stroage in the aquifer and recharge would be impossible when the apex of the cone reaches the surface.

It is therefore necessary to study the rate of the rise of the apex of the cone of impression during recharge of wells. We took the approach of a simple mathematical model having generalized boundary conditions and internal properties similar to those of the upper artesian aquifer.

Good data are virtually absent on the hydraulic properties of the upper artesian aquifer. These data can be obtained by special pumping tests, but we were not able to run these tests as a part of our studies. Therefore, we have estimated these data.

Coefficient of transmissibilities were estimated from specific capacity data using graphs prepared by Meyer (1963, p. 339) and Walton (1962, p. 13). The transmissibility for City well 2 is 150,000 gallons per day per foot; the transmissibility for City well 3 is 1,000,000 gallons per day per foot. We ran calculations for both values, regarding them as probable minimum and maximum values.

No means for estimating coefficient of storage could be used in Moscow basin; appropriate data do not exist. However, in most artesian aquifers, the values are in the range of 10^{-3} to 10^{-5}. We therefore selected the middle value, 10^{-4}. According to D.A. Myers (oral communication), members of the U.S. Geological Survey who are working on the geohydrology of the Columbia River Group consider 2.3×10^{-3} to be the best value of coefficient of storage. Therefore, our value probably is conservative.

The shape of the upper artesian aquifer was generalized as a rectangular body bounded by impermeable barriers on three sides---north, east, and south---

and open to the west (Fig. 7). The impermeable boundaries are the contacts between the upper artesian aquifer and the basement complex. The recharging site is about 10,000 feet from the north and south boundaries and about 8500 feet from the east boundary.

The probable buildup of the apex of the cone of impression was predicted using the modified non-equilibrium equation of Cooper and Jacob 1946 and the method of image wells (Ferris and others, 1962, p. 144-166). For the purposes of the calculation, we used a 100 day season and recharging rates of 1000 and 2000 gpm.

If City well 3 were used as the only recharge well, the buildup of the cone of impression in the vicinity of the well would be 24 feet after 100 days of recharging 1000 gpm and 45 feet after 100 days of recharging 2000 gpm. If City well 2 were used as the only recharge well, the buildup would be 62 feet at the end of 100 days of recharging 1000 gpm. Buildup of City well 2 for 2000 gpm was not calculated. By using the two wells in various combinations or recharge rates and days of recharge, probable buildups will fall somewhere between 60 and 25 feet.

CONCLUSIONS

Our proposed artificial recharge program is not simple. It is not cheap until its costs are compared with the costs of long-distance importation of surface water.

Our study is based on very little measured data and on a great deal of data that are either estimates or educated guesses. These data will need to be replaced by measured data before the program should be adopted.

Our preliminary study indicates naturally-available ground water plus artificially-recharged ground water obtained from nearby intermittent streams should meet the demands of Moscow basin until the year 2000 at a lower cost than long-distance importation of surface water. After the year 2000, the effluent of the City waste water treatment plant can be utilized to provide water sufficient to meet demands well into the 21st century.

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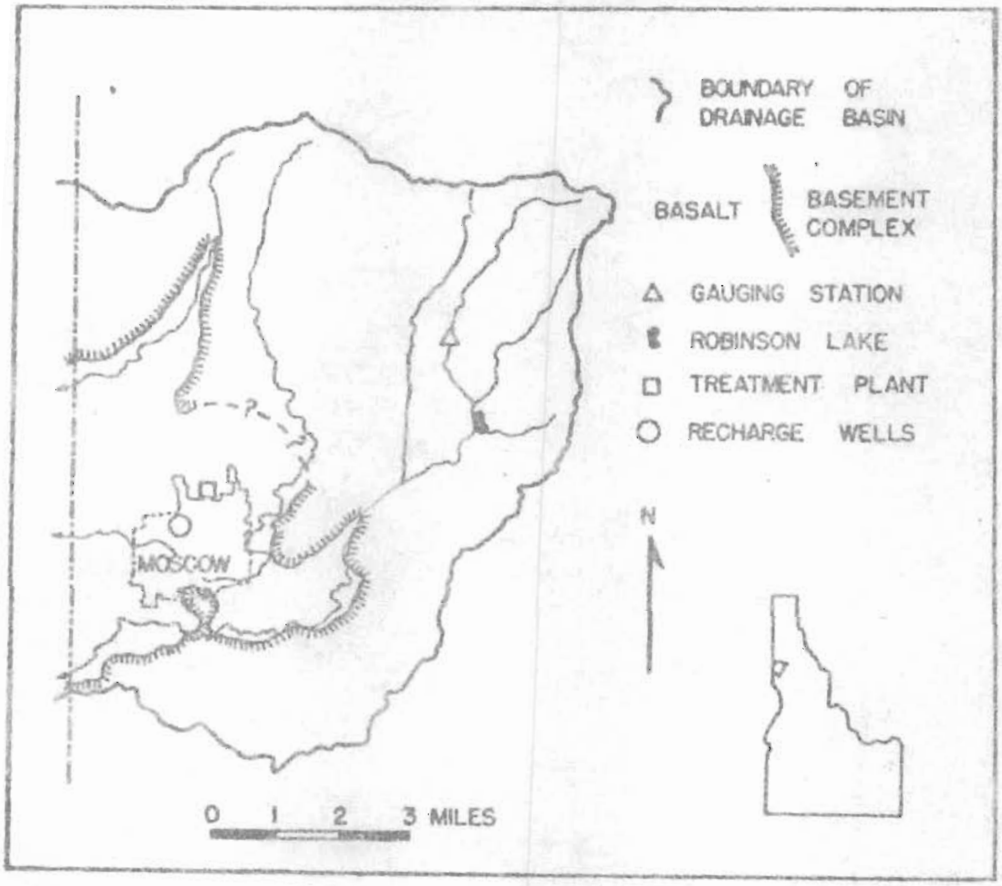

Figure 1. Index and location map of Moscow basin, Latah County, Idaho

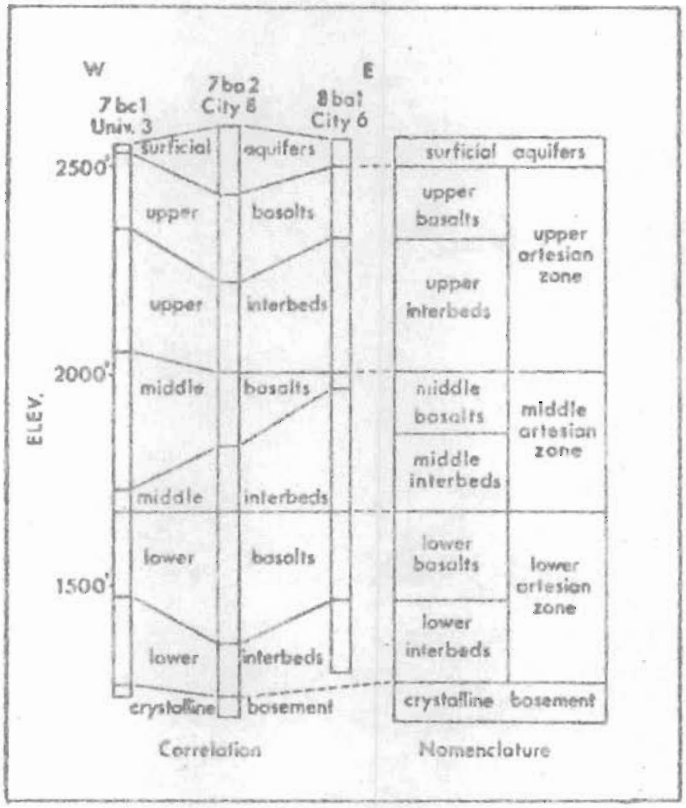

Figure 2. Hydrostratigraphic units, Moscow basin, Latah County, Idaho

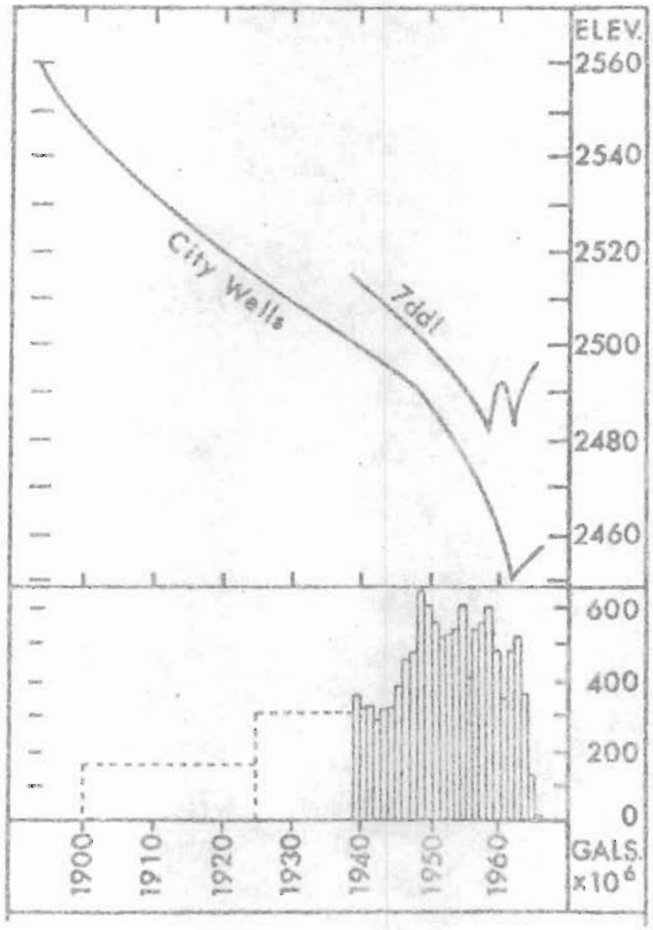

Figure 3. Water level trends (generalized) and water pumped, upper artesian aquifer, Moscow basin, Latah County, Idaho, 1896-1966.

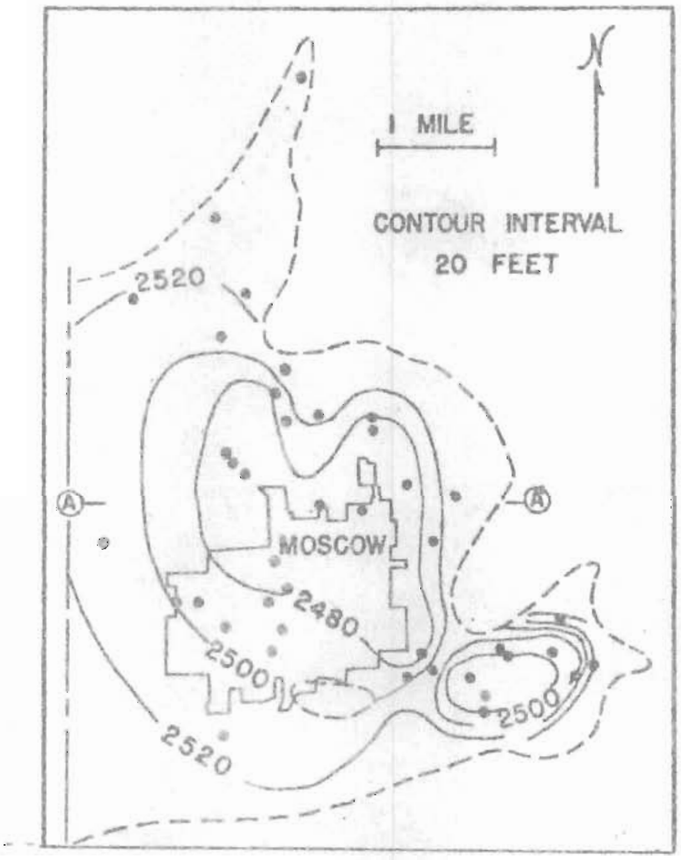

Figure 4. Piezometric surface, upper artesian aquifer, Moscow basin, Latah County, Idaho. Data: 1966.

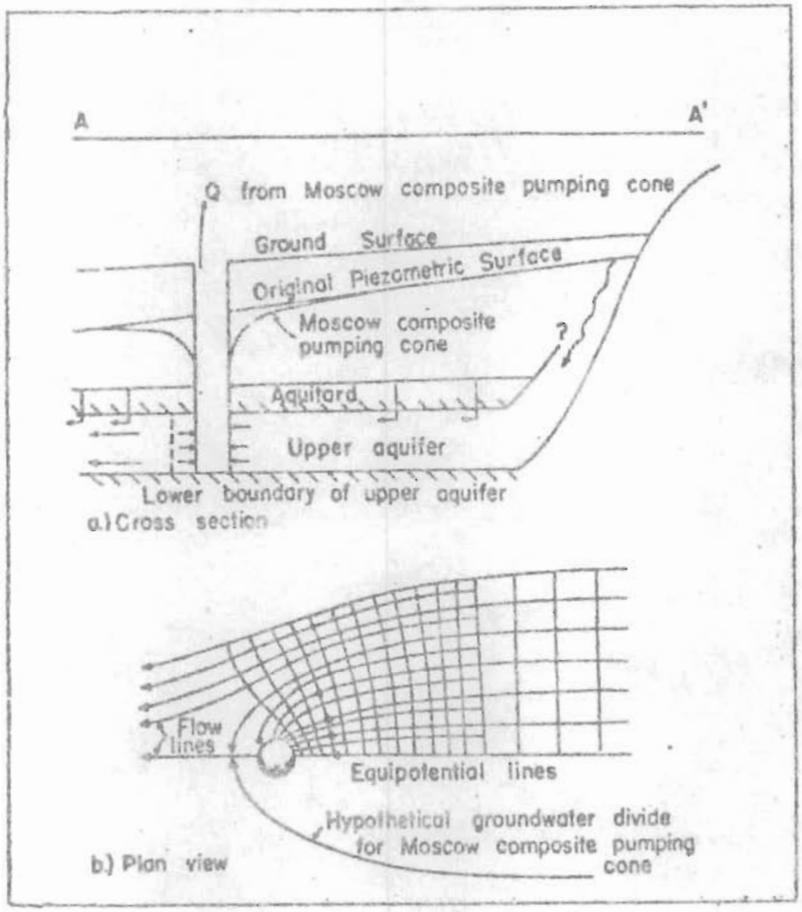

Figure 5. Schematic cross section and plan view of flow in upper artesian aquifer if composite cone of depression is assumed to not intercept all water leaving the basin. Moscow basin, Latah County, Idaho.

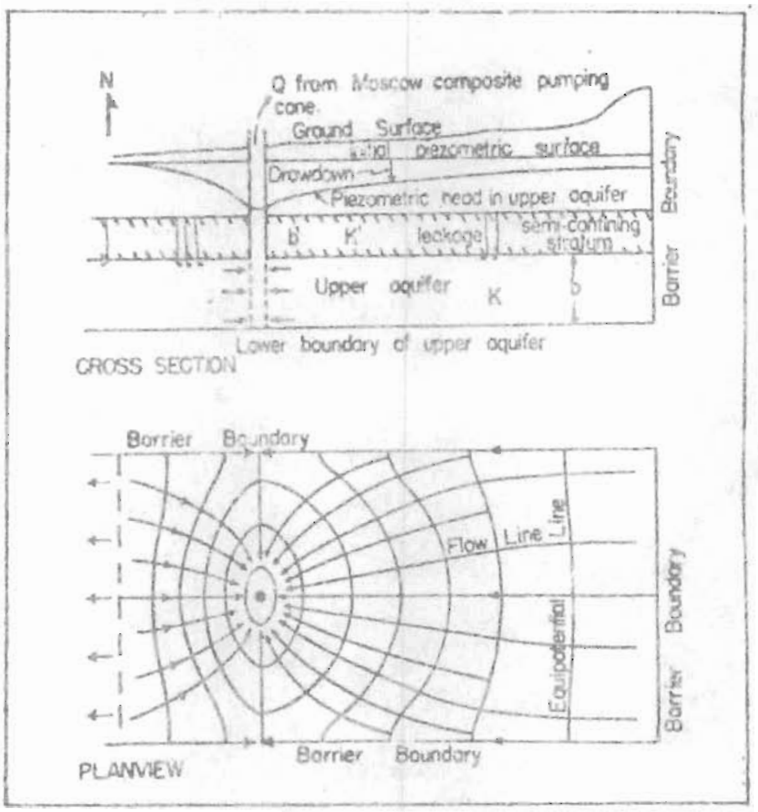

Figure 6. Schematic cross section and plan view of flow in upper artesian aquifer if composite cone of depression is assumed to intercept all water leaving the basin. Moscow basin, Latah County, Idaho.

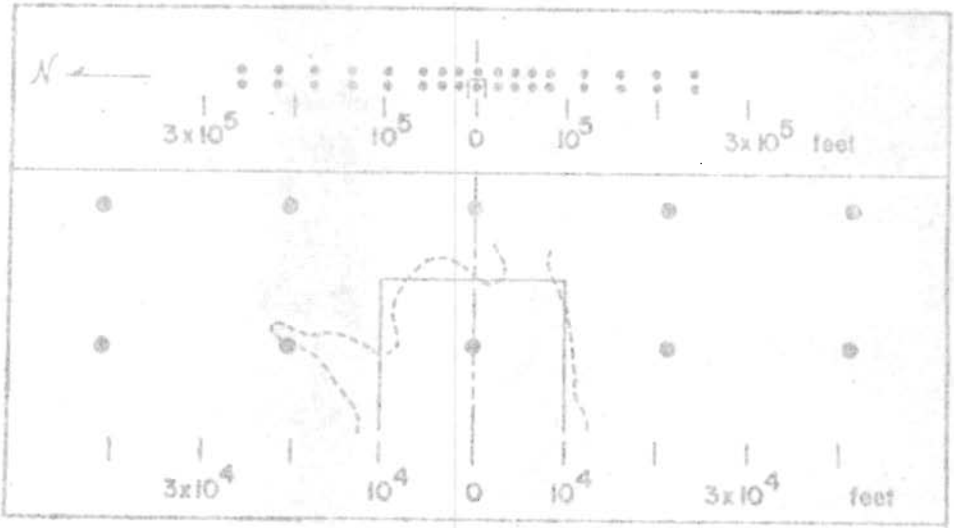

Figure 7. Aquifer boundaries and image well array for mathematical model study of recharging upper artesian aquifer at City of Moscow pumping plant. Moscow basin, Latah County, Idaho