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FIELD REPORT

Groundwater Survey and Hydrogeologic Characterization of the Kosaman and Berdykol Wellfields, Kazakstan

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1

Contents

Information iii

Abbreviations and Acronyms iv

Executive Summary v

Section **Page**

1 Introduction 1-1

2 Hydrogeologic Conditions of the Tolagaisk Basin 2-1
Hydrostratigraphic Units 2-1
Groundwater Flow Conditions 2-3
Groundwater Quality 2-3

3 Numerical Model of the Tolagaisk Basin 3-1
Model Grid 3-1
Hydrogeologic Properties 3-1
Boundary Conditions 3-1
Groundwater Budget 3-2

4 Model Calibration 4-1

5 Evaluation of Long-Term Effects of Pumping 5-1
Simulated Scenarios 5-1
Effects on Groundwater Levels 5-2
Effects on Groundwater Quality 5-2

6 Conclusions and Recommendations 6-1
Conclusions 6-1
Recommendations 6-1

Appendix A: Figures

Appendix B: Tables

Appendix C: Works Cited

Contents / continued

List of Figures in Appendix A

1 Study Area Location Map
2 Structural Map of the Study Area
3 Generalized Geologic Map
4 Hydrogeologic Cross Section
5 Hydrogeologic Map of the Study Area
6 Transmissivity Map - Lower Aquifier
7 Water Level Contour Map for 1971-75 - Upper and Lower Aquifiers (undivided)
8 Finite-Element Model Grid
9 Simulated Water Levels - Upper Aquifier (Calibration Scenario)
10 Simulated Water Levels - Lower Aquifier (Calibration Scenario)
11 Scatter Diagram of Simulated versus Measured Groundwater Elevations
12 Simulated Drawdowns - Lower Aquifier (Current Operating Conditions)
13 Simulated Drawdowns - Lower Aquifier (Proposed Operating Conditions)
14 Simulated Water Levels - Lower Aquifier (Proposed Operating Conditions)
15 Simulated Groundwater Pathlines from 1,000 mg/L TDS Concentration Contour After 50 Years - Lower Aquifier (Current Operating Conditions)
16 Simulated Groundwater Pathlines from 1,000 mg/L TDS Concentration Contour After 10 Years - Lower Aquifier (Proposed Operating Conditions)
17 Simulated Groundwater Pathlines from 1,000 mg/L TDS Concentration Contour After 20 Years - Lower Aquifier (Proposed Operating Conditions)
18 Simulated Groundwater Pathlines from 1,000 mg/L TDS Concentration Contour After 50 Years - Lower Aquifier (Proposed Operating Conditions)

List of Tables in Appendix B

1 Summary of Aquifier Testing Results
2 Conceptual Model of the Tolagaisk Basin

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Abbreviations and Acronyms

Abbreviations

in.	inches
km	kilometer
m/day	meters per day
mg/L	milligrams per liter
mm	millimeter
m^2/day	square meters per day
m^3/day	cubic meters per day

Acronyms

bgs	below ground surface
EPT	Environmental Policy and Technology
GOK	Government of Kazakstan
gpm	gallons per minute
MINGEO	Kazakstan Ministry of Geology (translated acronym)
MOU	Memorandum of Understanding
msl	mean sea level
RMS	root mean squared
TDS	Total Dissolved Solids
USAID	United States Agency for International Development
USG	United States Government

Executive Summary

In accordance with the Memorandum of Understanding (MOU) between the U.S. Government (USG) and the Government of Kazakstan (GOK), the U.S. Agency for International Development (USAID) is currently allocating funds for improvements to the potable water systems in and around the cities of Aralsk and Novokazalinsk in the Kzyl Orda Oblast of western Kazakstan. Potable water supplies for the cities of Aralsk and Novokazalinsk are dependent upon groundwater extracted from the Kosaman and Berdykol Wellfields, which are located northeast of the Aral Sea, within the Tolagaisk Groundwater Basin. Therefore, the long-term yield of the basin groundwater resource is of critical importance.

A conceptual numerical model of the Tolagaisk Basin was developed by Environmental Policy and Technology (EPT) Project personnel in order to assess the life of the groundwater resource under the current and proposed operating conditions. The results of this work provide a rough order-of-magnitude estimate of the long-term safe yield of the regional groundwater resource currently tapped by the Kosaman and Berdykol Wellfields.

The model was developed based on the report prepared by the Kazakstan Ministry of Geology (MINGEO)[1] and supplemented by data collected by EPT teams during recent visits to the site, June-September 1995. Following the teams' return to the United States, the data was evaluated and the model developed.

The Lower Aquifier is the principal water-bearing unit of the Tolagaisk Basin, and serves as the source of groundwater for the Kosaman and Berdykol Wellfields. The aquifer is comprised of fine- to coarse-grained sand interbedded with layers of clay and sandstone. The thickness of the aquifer ranges from 30 to 50 meters (m). Groundwater in the aquifer occurs under confined conditions with piezometric heads ranging from about 160 to 200 m above the top of the aquifer. Hydraulic conductivity ranges from 0.5 to 15 m/day. Transmissivity ranges from 200 to 400 square meters per day (m^2/day).

Groundwater quality is controlled primarily by the proximity to the recharge area in the axis of Tolagaisk Anticline, with generally low total dissolved solids (TDS) concentrations encountered in the vicinity of the anticline. TDS rise with increasing distance from this area. The Lower Aquifier is characterized by relatively good water quality in the vicinity of the Tolagaisk Anticline, with values of TDS ranging between 300 and 500 milligrams per liter (mg/L).

A simplified numerical model of the Tolagaisk Basin was developed by EPT Project personnel using the Micro-Fem finite-element code. The model was calibrated to the available water level data under no pumping scenario.

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[1] Kazakstan Ministry of Geology (MINGEO). Aktyubinsk Expedition, 1976. Water Supply Evaluation in the Tolagaisk Basin based on Investigations Performed 1971-76.

Two groundwater extraction scenarios were simulated with the calibrated model to assess the effect of pumping on groundwater levels and water quality:

1) current operating conditions – about 13,000 cubic meters per day (m^3/day) at the Kosaman Wellfield and 3,000 m^3/day at the Berdykol Wellfield

2) proposed operating conditions – about 46,400 m^3/day at the Kosaman Wellfield, and 7,600 m^3/day at the Berdykol Wellfield

Results of simulations for Scenario 1, Current Operating Conditions, indicate maximum drawdowns of about 15 m at the Kosaman Wellfield, and about 5 m at the Berdykol Wellfield. These values agree with the drawdowns currently measured in the field, and the system may have reached steady state conditions for this pumpage.

For Scenario 2, Proposed Operating Conditions, maximum water level drawdowns will reach about 45 m at the Kosaman Wellfield, and about 15 m at the Berdykol Wellfield. It has been reported that the casing diameter decreases from 12 to 6 in. at a depth of about 145 m below ground surface (bgs) at Kosaman, and 85 m bgs at Berdykol. Because the average diameter of proposed pumps is about 6 in., pumps will have to be installed above the restricted section. Simulated drawdowns at both wellfields are above the restricted sections, which indicates that current well designs should be adequate to support the proposed pumpage on a sustained long-term basis.

The salinity of groundwater is the primary water quality issue in the Tolagaisk Basin. Under Scenario 1, Current Operating Conditions, the simulations indicate that the wellfields will not be impacted by the high salinity water for at least 50 years. Under Scenario 2, Proposed Operating Conditions, simulation results indicate that pumping at the Kosaman Wellfield will reverse the gradient in the vicinity of the wellfield, and will likely cause migration of high Total Dissolved Solids (TDS) water towards the wells. Saline water will not likely impact the Kosaman Wellfield for 20 to 50 years. Based on model simulations, the Berdykol Wellfield will not be impacted by the high salinity water for at least 50 years.

To summarize, modeling results indicate that increase of groundwater production at the Kosaman and Berdykol Wellfields may be achieved given current well construction designs, but may cause migration of high TDS water towards the wells. This migration will not likely have a significant impact on quality of produced water within at least 20 years. Development of a comprehensive monitoring program is recommended in the future to monitor migration of the saline plume in the vicinity of the wellfields.

It is important to understand that groundwater modeling described above is based on the limited data, and must be viewed as reconnaissance level. In the future, more detailed review work appears warranted if large capital expenditures for the water supply system are contemplated, including review of existing modeling work and updated regional water level and water quality data that is currently unavailable to USAID.

Section 1
Introduction

Editor's Note regarding figures and tables: All figures referred to in Sections 1 through 5 are located in Appendix A; all tables are located in Appendix B.

In accordance with the MOU between the USG and the GOK, USAID is currently allocating funds for improvements to the potable water systems in and around the cities of Aralsk and Novokazalinsk in the Kzyl Orda Oblast of western Kazakstan (Figure 1). The specific activities listed in the MOU include improvements of booster pumping stations along the main transmission pipeline, installation of new chlorination equipment and improvements to the water distribution systems. In addition, Kazakstan officials have contemplated replacement and/or major repair of the transmission pipeline connecting the wellfields to points of consumption.

Potable water supplies for the cities of Aralsk and Novokazalinsk are dependent upon groundwater from the Kosaman and Berdykol Wellfields, which are located northeast of the Aral Sea, within the Tolagaisk Groundwater Basin (Figure 1). Therefore, the long-term yield of the basin groundwater resource is of critical importance.

A conceptual numerical model of the Tolagaisk Basin was developed by EPT Project personnel in order to assess the life of the groundwater resource under the current and proposed operating conditions. The results of this work provide a rough order-of-magnitude estimate of the long-term safe yield of the regional groundwater resource currently tapped by the Kosaman and Berdykol Wellfields. The model was developed based on the report prepared by the Kazakstan Ministry of Geology (MINGEO, 1976) and supplemented by data collected by EPT teams during recent visits to the site, June-September 1995. Following the teams' return to the United States, the data was evaluated and the model developed.

This report summarizes the results of our modeling effort. Because there was not sufficient time and data to conduct a comprehensive study, the model was significantly simplified. The results of this work provide a rough order-of-magnitude estimate of the long-term safe yield of the regional groundwater resource currently tapped by the wells.

Section 2
Hydrogeologic Conditions of the Tolagaisk Basin

The Tolagaisk Basin is located within Aralo-Turgaisk plain, which slopes gently to the southeast. The landscape of the area results from folding and faulting of the basement rock, and is comprised of a system of synclines and anticlines. The major tectonic features of the study area include the Tolagaisk Anticline, which is bounded by the Toguzskiy Syncline on the west, and Chokusinskiy Syncline on the east (Figure 2). These structures are elongated from north to south. Surface elevations in the area range from 80 m above mean sea level (msl) to as high as 327 m above msl.

The description of the hydrostratigraphic units, groundwater flow conditions, and groundwater quality of the Tolagaisk Basin presented in this section is based on the review of hydroge-ologic characterization report prepared by local geologists in 1976 (MINGEO, 1976), and a limited amount of field work performed at the well sites in 1995 as part of the EPT Project.

2.1 Hydrostratigraphic Units

The Tolagaisk Basin consists of Mesozoic, Tertiary and Quaternary marine and continental sediments deposited on a basement of pre-Tertiary (possibly Mesozoic) crystalline rock. Generalized geologic map and cross-section of the study area are presented as Figures 3 and 4, respectively. A hydrogeologic map of the study area is presented as Figure 5. An important feature of the Tolagaisk Basin is the lens of unsaturated aeolian sands located on the western slope of the Tolagaisk anticline, and elongated from the north to the south (Figure 3). The sands are very permeable, and provide favorable conditions for surface infiltration, which is the major source of fresh water replenishment to the groundwater basin.

The principal aquifer in the Tolagaisk Basin is Upper Eocene in age. Groundwater from overlaying aquifers of Quaternary, Pliocene, and Eocene age, and from underlying Cretaceous aquifiers, are not currently used due to high salinity. The aquifiers and aquitards of the Tolagaisk Basin are described in this section in downward stratigraphic succession, from youngest to oldest. The saline water aquifiers of Cretaceous age are separated from the principal aquifier by dense clays of the Upper Eocene and do not significantly impact the overlaying aquifiers, and therefore not considered in this evaluation.

2.1.1 Water Table Aquifer

The Water Table aquifer within the study area is of Upper Pliocene/Middle Quaternary age (Figures 3 and 4). It is overlain by unsaturated aeolian sands, which provide favorable conditions for surface infiltration. The aquifer is comprised of alluvial sediments represented by interbedded sands and clays. The thickness of the aquifer ranges from 5 to 15 m. Hydraulic conductivity ranges from 0.1 to 10 m/day, and values of transmissivity range from 80 to 200 m^2/day. This unit is continuous throughout the basin with the exception of a small area in the axis of the

Tolagaisk anticline, where it pinches out and the Upper Bodrukskiy Formation outcrops on the surface (Figures 3 and 5).

2.1.2 Upper Aquitard

The Upper Aquitard is represented by the Alminskiy Formation of the Upper Eocene (Figures 3 and 4). The aquitard is comprised by dense clays with a thickness ranging from 80 to 160 m, and hydraulic conductivity of about 0.02 m/day. This layer pinches out in the axis of the Tolagaisk Anticline and in the eastern portion of the Basin, where deposits of the Upper Bodrukskiy Formation are directly overlaid by the Water Table Aquifer, or outcrop on the surface (Figures 5).

2.1.3 Upper Aquifer

The Upper Aquifer is the uppermost water-bearing unit of the Upper Bodrukskiy Formation, and is of Upper Eocene age (Figure 3 and 4). The aquifer is comprised of medium- to fine-grained sands interbedded with layers of clay. The thickness of the aquifer ranges from 20 to 45 m. Groundwater occurs under confined conditions with piezometric heads ranging from about 75 to 150 m above the top of the aquifer.

Hydraulic conductivity ranges from 0.5 to 15 m/day. The main area of recharge is located in the axis of the Tolagaisk Anticline where the Upper Bodrukskiy Formation outcrops on the surface, or directly overlaid by the Water Table Aquifer (Figure 3 and 5). The aquifer discharge via marshes and springs occurs in the areas to the west and southeast of the Tolagaisk Anticline (Figure 5).

2.1.4 Middle Aquitard

The Middle Aquitard is made up of deposits of the Upper Bodrukskiy Formation. This unit separates the Upper Aquifer from the Lower Aquifer (Figure 4). The aquitard is comprised by dense clays with a thickness of about 25 to 50 m, and conductivity of about 0.0086 m/day.

2.1.5 Lower Aquifer

The Lower Aquifer is the deepest unit of the Upper Bodrukskiy Formation. It is the principal water-bearing unit of the Tolagaisk Basin, and serves as the source of groundwater for the Kosaman and Berdykol Wellfields. The aquifer is comprised of fine- to coarse-grained sand interbedded with layers of clay and sandstone. The thickness of the aquifer ranges from 30 to 50 m. Groundwater in the aquifer occurs under confined conditions with piezometric heads ranging from about 160 to 200 m above the top of the aquifer. Hydraulic conductivity ranges from 0.5 to 15 m/day.

The transmissivity distribution map prepared as part of the hydrogeologic characterization report (MINGEO, 1976) is presented in Figure 6. Based on this map, transmissivity of the Lower Aquifer ranges from about 200 to about 400 m^2/day). Aquifer tests performed at the well sites as part of the EPT Project indicate that transmissivity in the vicinity of the wellfields ranges from about

350 to about 430 m^2/day, which agrees with the data presented on the accompanying map (Table 1).

Recharge of the aquifer occurs in the axis of the Tolagaisk Anticline, where the Upper Aquitard pinches out and the Upper Bodrukskiy Formation outcrops on the surface, or is directly overlaid by the Water Table Aquifer (Figures 3 and 5). The aquifer discharges via marshes and springs in areas to the west and southeast of the Tolagaisk Anticline (Figure 5).

2.1.6 Lower Aquitard

The Lower Aquitard is comprised of deposits of the Lower Bodrukskiy Formation, Middle and Upper Eocene age. This unit separates the Upper Bodrukskiy Formation from the saline water aquifers of Cretaceous age. The aquitard consists of clays with layers of sandstone and sand. The thickness of this unit ranges from 100 to 150 m. It is continuous throughout the study area and serves as a regional aquitard (Figure 4).

2.2 Groundwater Flow Conditions

The only available water level contour map of the Tolagaisk Basin was prepared 1971 to 1975 as part of the hydrogeologic characterization report (MINGEO, 1976). This map represents composite water levels for the Upper and Lower aquifers. Because the map was prepared prior to construction of the Kosaman and Berdykol Wellfields, it represents the undisturbed (non-pumping) groundwater flow conditions in the Tolagaisk basin (Figure 7).

From the area of recharge in the axis of the Tolagaisk anticline groundwater flows to the west and south-west, and to the south-east, towards the discharge areas within the syncline structures. Groundwater gradients range from as high as 0.005 at the area of recharge to an average of 0.0008 throughout the rest of the basin (Figure 7).

2.3 Groundwater Quality

For most aquifers of the Tolagaisk Basin, the groundwater quality is controlled primarily by the proximity to the recharge area in the axis of the Tolagaisk Anticline, with generally low TDS concentrations encountered in the vicinity of the anticline. TDS increase significantly in the peripheral portions of the basin.

2.3.1 Water Table Aquifer

The Water Table Aquifer is characterized by the relatively low TDS of about 150 to 1,000 mg/L in the vicinity of the Tolagaisk Anticline. TDS values increase significantly along the peripheral portions of the basin.

2.3.2 Upper Aquifer

This aquifer is also characterized by low TDS concentrations of 600 to 1,000 mg/L in the proximity to the recharge area in the axis of the Tolagaisk Anticline. The values of TDS increase significantly with increasing distance from the zone of recharge, and reach 3,300 mg/L at the Berdykol site, and as high as 4,300 mg/L at the Kosaman site.

2.3.3 Lower Aquifer

The Lower Aquifer throughout the basin is characterized by relatively good water quality. Similarly to the overlying aquifers, values of TDS (300 to 500 mg/L) are lowest in the vicinity of the main recharge area in the axis of the Tolagaisk Anticline. TDS concentration contours for the Lower Aquifer are presented on Figure 5. Good water quality of less than 1,000 mg/L, however, is maintained in this aquifer within the area south and southeast of the Tolagaisk Anticline (Figure 5). The boundary of 1,000 mg/L TDS concentration zone is located about 7 kilometers (km) west and 6.5 km south from the center of the Kosaman Wellfield, and about 8 km east from the center of the Berdykol Wellfield (Figure 5).

Section 3
Numerical Model of the Tolagaisk Basin

A simplified numerical model of the Tolagaisk Basin was developed using the MicroFem finite-element code.[2] The numerical input data sets including model grid, hydrogeologic properties, boundary conditions, and groundwater budget are presented below.

3.1 Model Grid

The triangular, finite-element grid used in the Tolagaisk Basin Model is illustrated in Figure 8. The intersections of the grid lines are referred to as nodes, where groundwater levels are simulated by the model. The area between the grid lines is referred to as an element, which represent sections of aquifers and aquitards. The grid has been developed to account for basin boundaries, and locations of extraction wells. The spacing between nodes in the vicinity of the Kosaman and Berdykol Wellfields is much smaller then in the rest of the area to allow for more accurate estimates of drawdowns near the wells. The grid consists of six layers with a total of 7,400 nodes, 14,730 elements. A correlation between the hydrostratigraphic units and model layers is presented in Table 2.

3.2 Hydrogeologic Properties

The hydrogeologic properties of the Tolagaisk Basin are described in Section 2. These ranges of properties were used for developing initial data sets of the numerical model, and adjusted during model calibration to achieve the best agreement between the observed and simulated water levels (see Section 4). The assignment of hydrogeologic parameters for each of the hydrostratigraphic units resulting from model calibration are presented in Table 2.

3.3 Boundary Conditions

Boundary conditions of the model were defined based on available water level information (Figure 7). As mentioned previously, groundwater flow in the Tolagaisk Basin is controlled primarily by recharge along the axis of the Tolagaisk Anticline, and by discharge in the western and southeastern portions of the basin. Surface recharge was assigned to Layer 1 of the model (the Water Table aquifer). Discharge boundaries were simulated as outflow nodes in the western and southeastern portions of the basin.

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[2] Hemker, C.J., and van Elburg, H. Microcomputer Multilayer Finite Element Groundwater Model. 1988.

3.4 Groundwater Budget

The groundwater budget of the Tolagaisk Basin consists of a recharge component, represented primarily by the surface recharge, and a discharge component, represented by the natural discharge and groundwater extraction.

3.4.1 Surface Recharge

The rate of surface recharge was defined based on the average rainfall data available for the study area, and then adjusted during model calibration. A recharge rate of 46 millimeters (mm) per year was assigned to the area in the vicinity of the Tolagaisk Anticline. A recharge rate of 16 mm per year was assigned to the rest of the basin. The total simulated surface recharge to the basin is about 181,590 m^3/day.

3.4.2 Natural Discharge

As mentioned previously, the natural discharge of the aquifers within the Tolagaisk Basin occurs via marshes and springs in the areas to the west and southeast of the Tolagaisk Anticline. The discharge is simulated by the model as fixed head outflow nodes. Assuming steady-state groundwater flow conditions, the natural discharge in the basin is generally equal to the surface recharge minus groundwater extraction. Under steady-state flow conditions, with no pumping in the Tolagaisk Basin, the rate of natural discharge is equal to the surface recharge of 181,590 m^3/day.

3.4.3 Groundwater Extraction

Two groundwater extraction scenarios were simulated with the Tolagaisk Basin model:

1) current operating conditions
2) proposed operating conditions

The scenarios are described at more length in Section 5. Groundwater extraction is simulated as a nodal sink and assigned to Layer 5 of the model (Lower Aquifer). Locations and spacing between the pumping nodes are based on the locations and spacing between the wells at the Kosaman and Berdykol Wellfields. The Kosaman Wellfield is simulated as a line of pumping nodes oriented from the north to the south with a spacing of 200 m between the nodes. The Berdykol Wellfield is simulated as a line of pumping nodes oriented from the west to the east with a nodal spacing of 350 m.

Section 4
Model Calibration

Groundwater flow calibration was performed to demonstrate that the numerical model can reproduce the observed flow conditions in the Tolagaisk Basin. The groundwater flow was calibrated to the composite water level contour map for the Upper and Lower Aquifers (undivided) presented in Figure 7. As mentioned previously, this map was prepared as part of regional hydrogeologic investigations conducted between 1971 and 1975, prior to construction of the Kosaman and Berdykol Wellfields. Therefore, it represents non-pumping conditions in the Tolagaisk Basin.

To reproduce water levels presented on Figure 7, non-pumping groundwater flow conditions were simulated. It was assumed that the difference between water levels in the Upper and Lower aquifers is negligible under non-pumping conditions. Therefore, groundwater flow in the Upper and Lower aquifers was calibrated to the composite water levels presented on Figure 7. Steady-state groundwater flow conditions were assumed for model simulations based on the available time-series water level data (MINGEO, 1976).

To achieve a better agreement between observed and simulated water levels, hydrogeologic properties of the model were adjusted within a range of values compatible with the conceptual model of the basin. The model parameters adjusted during calibration included hydraulic conductivity and surface recharge. Calibrated model data sets are presented in Table 2.

Results of the groundwater flow calibration are presented in Figures 9 and 10 for the Upper and Lower aquifers, respectively. A root mean squared (RMS) error of the differences between the simulated and measured water level elevations was calculated to assess how close the model simulation results are to the observed flow conditions. The RMS error of about 5.60 m was estimated for the final calibration run. This RMS error is acceptable for the Tolagaisk Basin, where about 100 m of head difference is present between the northeastern and southwestern boundaries.

A scatter diagram of measured versus simulated groundwater elevations is presented in Figure 11. A line of perfect agreement ($x_{value} = y_{value}$) is also shown on this plot. The scatter of data points is located relatively close to this line, which indicates a generally good agreement between the simulated and measured water level elevation. Comparison of simulated and observed horizontal gradients indicates that the simulated average gradient across the central portion of the basin of about 0.001 is similar to the observed average gradient of 0.0008 estimated from the available water contour map.

The model was also calibrated to current operating conditions. During summer 1995 fieldwork, water levels were observed to be about 18 m below land surface at the Kosaman and Berdykol well sites. Existing reports indicate that the water levels were at or near ground surface in the Kosaman area, and 15 m below ground surface at Berdykol, at the time the wells were installed. The simulated drawdowns of 10 to 15 m at the Kosaman and 5 m at Berdykol therefore correspond well to observed data. The model was also calibrated to aquifer test data collected in Sum-

15

mer 1995, providing good agreement between simulated and observed data. Overall model calibration results indicate that, although local variations may occur, the regional flow pattern is reasonably well simulated by the model.

Section 5

Evaluation of Long-Term Effects of Pumping

This section presents the results of long-term effects of pumping at the Kosaman and Berdykol Wellfields on groundwater levels and water quality of the Tolagaisk Basin. The long-terms effects of pumping were evaluated under the current and proposed pumping scenarios. A description of these scenarios and an evaluation of long-term effects of pumping on water levels and water quality are presented below.

5.1 Simulated Scenarios

The current and proposed groundwater extraction scenarios from the Kosaman and Berdykol Wellfields are described below.

5.1.1 Scenario 1: Current Operating Conditions

The current groundwater extraction rate in the Tolagaisk Basin is about 16,000 m^3/day, consisting of 13,000 m^3/day from the Kosaman Wellfield and 3,000 m^3/day from the Berdykol Wellfield. An average of seven and two wells are being pumped at the Kosaman and Berdykol Wellfields, respectively. To simulate the current operating conditions, an average extraction rate of 1,857 m^3/day/well [340 gallons per minute per well (gpm/well)] was assigned to seven wells (nodes) at the Kosaman site, and an average extraction rate of 1,500 m^3/day/well (275 gpm/well) was assigned to two nodes at the Berdykol site.

5.1.2 Scenario 2: Proposed Operating Conditions

The wellfield improvement program proposes total extraction of about 54,000 m^3/day (46,400 m^3/day at the Kosaman Wellfield, and 7,600 m^3/day at the Berdykol Wellfield). For modeling purposes it was assumed that a total of about 25 and four wells would be pumped at the Kosaman and Berdykol Wellfields, respectively. The proposed pumping rates are listed below:

Kosaman Wellfield.

5 wells at 818 m^3/day/well (150 gpm/well)
15 wells at 1,909 m^3/day/well (350 gpm/well)
5 wells at 2,727 m^3/day/well (500 gpm/well)

Berdykol Wellfield.

4 wells at 1,909 m^3/day/well (350 gpm/well)

5.2 Effects on Groundwater Levels

To evaluate the long-term effects of pumping on groundwater levels, simulations of the Tolagaisk Basin model were performed under the pumping scenarios described above. The model simulations were performed under assumed steady-state groundwater flow conditions, which represent the most conservative estimate ("worst case") of drawdowns resulting from pumping (steady-state flow conditions assume that water levels have stabilized at the maximum depth). The estimated drawdowns are presented in Figures 12 and 13 for the current and proposed operating conditions, respectively.

5.2.1 Scenario 1: Current Operating Conditions

Figure 12 indicates that under the current operating conditions, the maximum drawdown will reach about 15 m at the Kosaman Wellfield and about 5 m at the Berdykol Wellfield. These values agree with the drawdowns measured in the field, which confirms the reliability of model estimates.

5.2.2 Scenario 2: Proposed Operating Conditions

Figure 13 indicates that under the proposed operating conditions, maximum water level drawdowns will reach about 45 m at the Kosaman Wellfield and about 15 m at the Berdykol Wellfield. The reported average depth to the top of the restricted well section (the pump resides in the upper, unrestricted well section) is about 145 m at Kosaman, and 85 m at Berdykol. In both of these wellfields, simulated drawdowns remain above the restricted well section.

In addition, current pump settings are reportedly at about 53 m bgs, which is less than maximum simulated drawdowns. Therefore, results of simulation indicate that current well designs and pump settings should be adequate to support Scenario 2 pumpage. Figure 14 indicates the drawdown effects of pumping on the regional groundwater flow pattern. Overall, simulation results indicate that the initial design flow rate of 54,000 m^3/day could be sustained on a long-term basis.

5.3 Effects on Groundwater Quality

The salinity of groundwater is the primary water quality issue in the Tolagaisk Basin. As discussed in Section 2, the Lower Aquifer in the vicinity of the wellfields is characterized by relatively low TDS concentrations. However, concentrations of TDS increase to over 1,000 mg/L west and south of Kosaman and also east of Berdykol (Figure 5). To evaluate the effects of pumping on TDS concentrations at the wellfields, the advective transport of TDS from the 1,000 mg/L concentration contour was simulated under the current and proposed operating conditions.

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater. Advective transport of TDS was simulated using the F3 model program included in the MicroFem software package. This program traces the path lines of individual "particles"

of groundwater on the basis of the groundwater flow fields simulated by the model. Assuming that dissolved substances such as TDS travel along with the water particles, migration of TDS over time can be traced by this program.

5.3.1 Scenario 1: Current Operating Conditions

Migration of TDS from the 1,000 mg/L concentration contour was simulated under the current operating scenario. The simulations indicate that the wellfields will not be impacted by the high salinity water for at least 50 years (Figure 15). Field testing at the wellfields in 1995 indicated that TDS in most wells is below 1,000 mg/L. Therefore, previous pumping of the wellfields for about 6 to 7 years did not cause significant deterioration of the water quality, which agrees with model results.

5.3.2 Scenario 2: Proposed Operating Conditions

Groundwater pathlines designating possible migration of TDS under the proposed operating conditions are shown on Figures 16 through 18 after 10, 20 and 50 years, respectively. These results indicate, that pumping at the Kosaman Wellfield will reverse the gradient in the vicinity of the wellfield, and will likely cause migration of high TDS water towards the wells. Saline water will not likely impact the Kosaman Wellfield after 10 years, but may reach some wells in the southern portion of the site after 20 and 50 years. Based on model simulations, the Berdykol Wellfield will not be impacted by the high salinity water for at least as long as 50 years.

5.3.3 Discussion

Estimates of TDS transport performed in this study represent a significant simplification of the natural system. Simulation of advective transport does not account for a number of processes controlling migration of solute in groundwater, such as dispersion, retardation, or degradation. Because TDS is largely conservative, concentrations will not be significantly affected by retardation or degradation. The process of mechanical dispersion, however, will cause a broadening of the TDS front, with resulting arrival times being somewhat earlier than those predicted by simple advection.

In addition, uncertainties associated with the current distribution of TDS in the basin (the most recent available TDS data are from 1971 to 1975), and the local variations in the simulated and observed flow fields, should be considered in evaluating model projections of TDS transport. Evaluation of the current TDS concentration data, and monitoring of TDS concentrations in the vicinity of the wellfields may be required to gain a better understanding of the effects of pumping on the groundwater quality.

Section 6

Conclusions and Recommendations

6.1 Conclusions

Under Scenario 1, Current Operating Conditions, the maximum drawdown will reach about 15 m at the Kosaman Wellfield, and about 5 m at the Berdykol Wellfield. These values agree with the drawdowns currently measured in the field, and the system may have reached steady state conditions for this pumpage.

Under Scenario 2, Proposed Operating Conditions, maximum water level drawdowns will reach about 45 m at the Kosaman Wellfield, and about 15 m at the Berdykol Wellfield. The reported average depth to the top of the restricted well section is about 145 m at Kosaman, and 85 m at Berdykol. Because the average diameter of proposed pumps is about 6 in., pumps should reside above the restricted well. Simulated dynamic water levels at both wellfields do not fall below the top of the restricted well section, which indicates that current well designs should be adequate to support the proposed pumpage on a sustained long-term basis.

The salinity of groundwater is the primary water quality issue in the Tolagaisk Basin. Under Scenario 1, Current Operating Conditions, the simulations indicate that the wellfields will not be impacted by the high salinity water for at least 50 years. Under Scenario 2, Proposed Operating Conditions, results indicate that pumping at the Kosaman Wellfield will reverse the gradient in the vicinity of the wellfield, and will likely cause migration of high TDS water towards the wells. Saline water will not likely impact the Kosaman Wellfield for 20 to 50 years. Based on model simulations, the Berdykol Wellfield will not be impacted by the high salinity water for at least 50 years. Development of the comprehensive monitoring program is recommended in the future to monitor migration of the saline plume in the vicinity of the wellfields.

6.2 Recommendations

All the simulations conducted above were based on limited available information and must be viewed as of reconnaissance level only. However, it is significant that this modeling work largely corroborates previous analytical modeling work performed by Russian and Kazakstan hydrogeologists. More detailed review work, including review of an existing Russian-language modeling report that has not been made available to EPT, appears warranted. This is particularly true in light of large capital expenditures for the water supply system planned in 1996 and beyond.

Appendixes

Appendix A
Figures

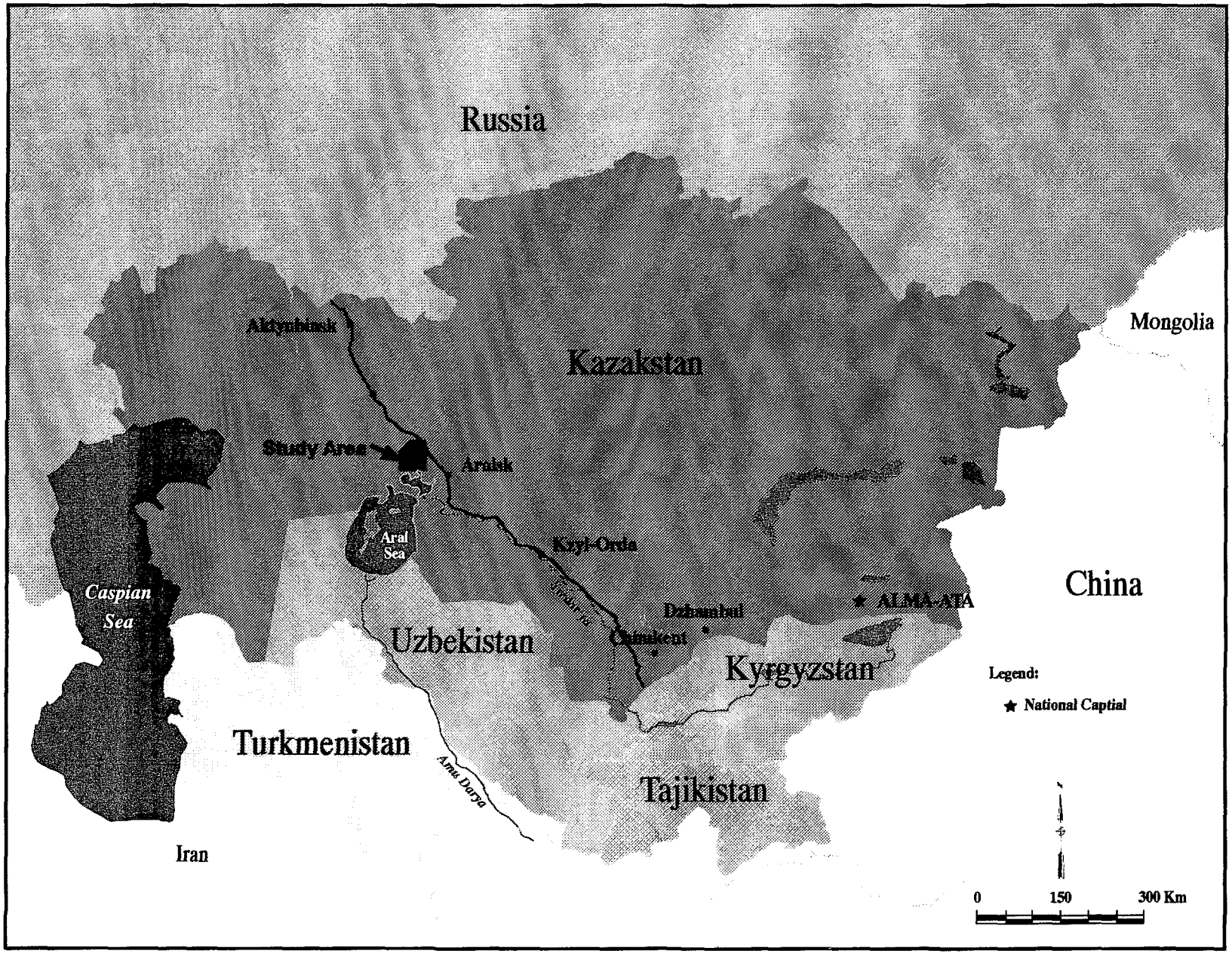
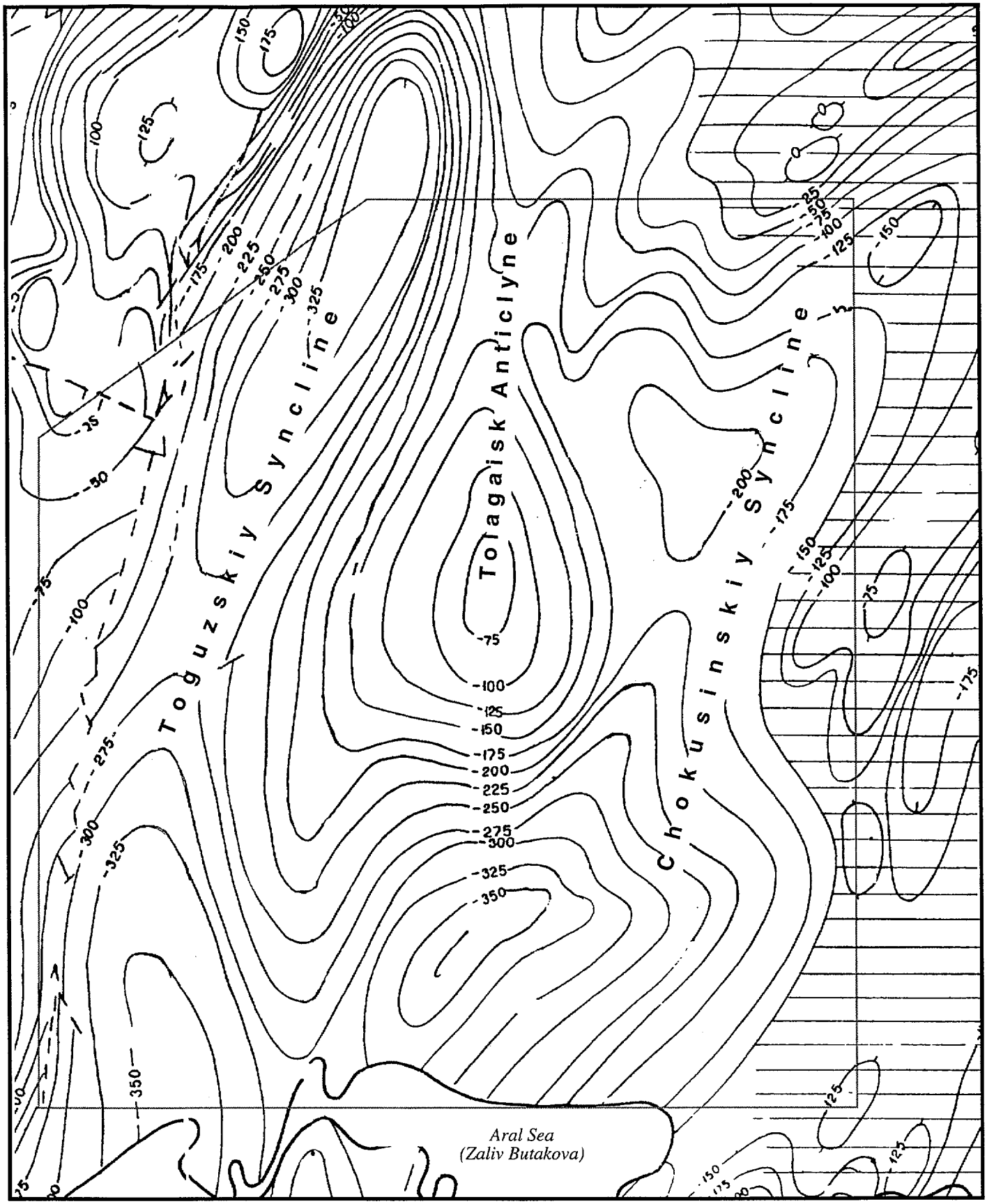


Figure 1
Study Area Location Map

m111600.a0.01/kazakastan 12/95

23



Study Area Boundary

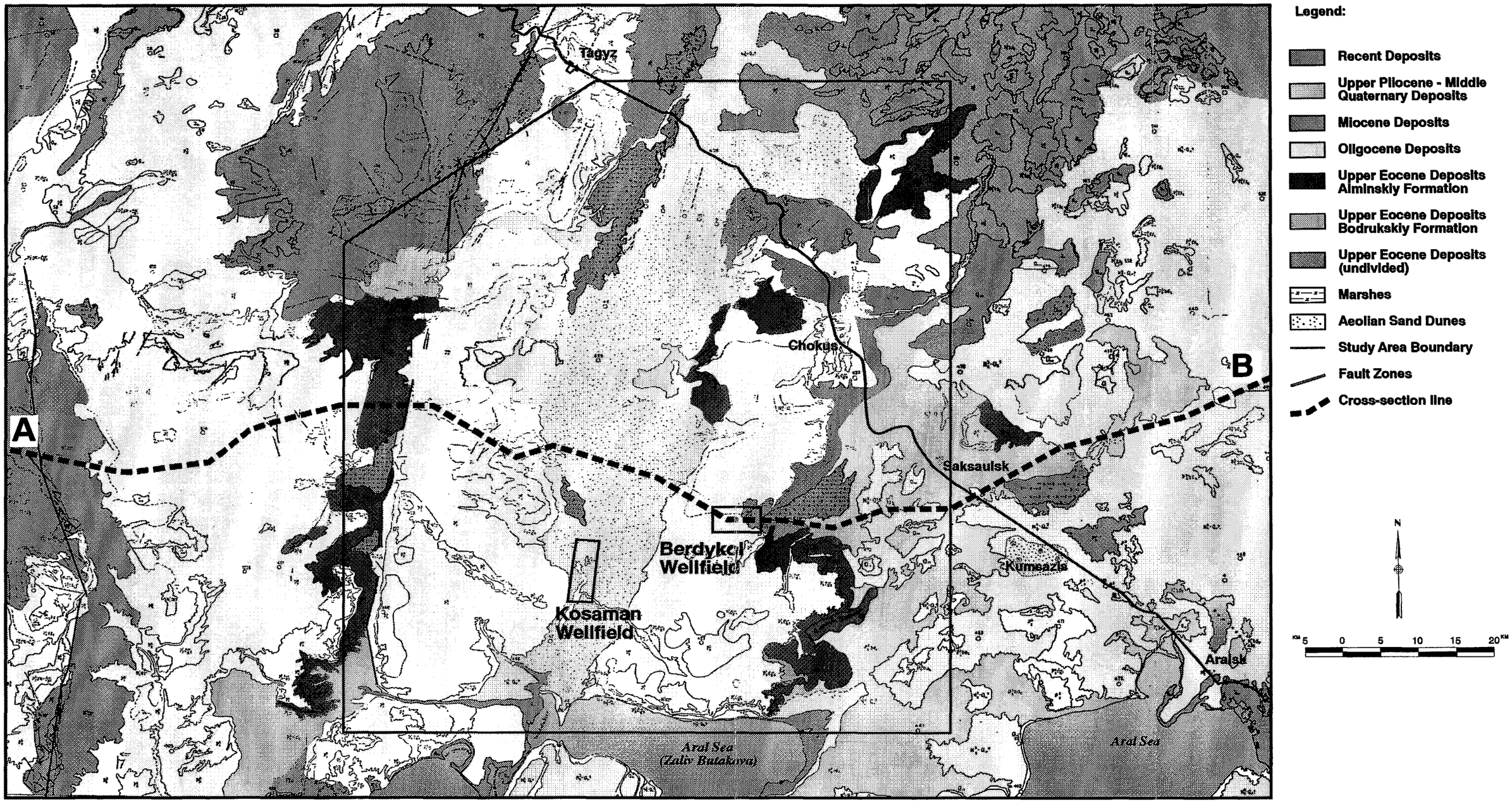
-350 Elevation contour of base of Tertiary deposits

KM 5 0 5 10 15 20 KM

Figure 2
Structural Map of the Study Area

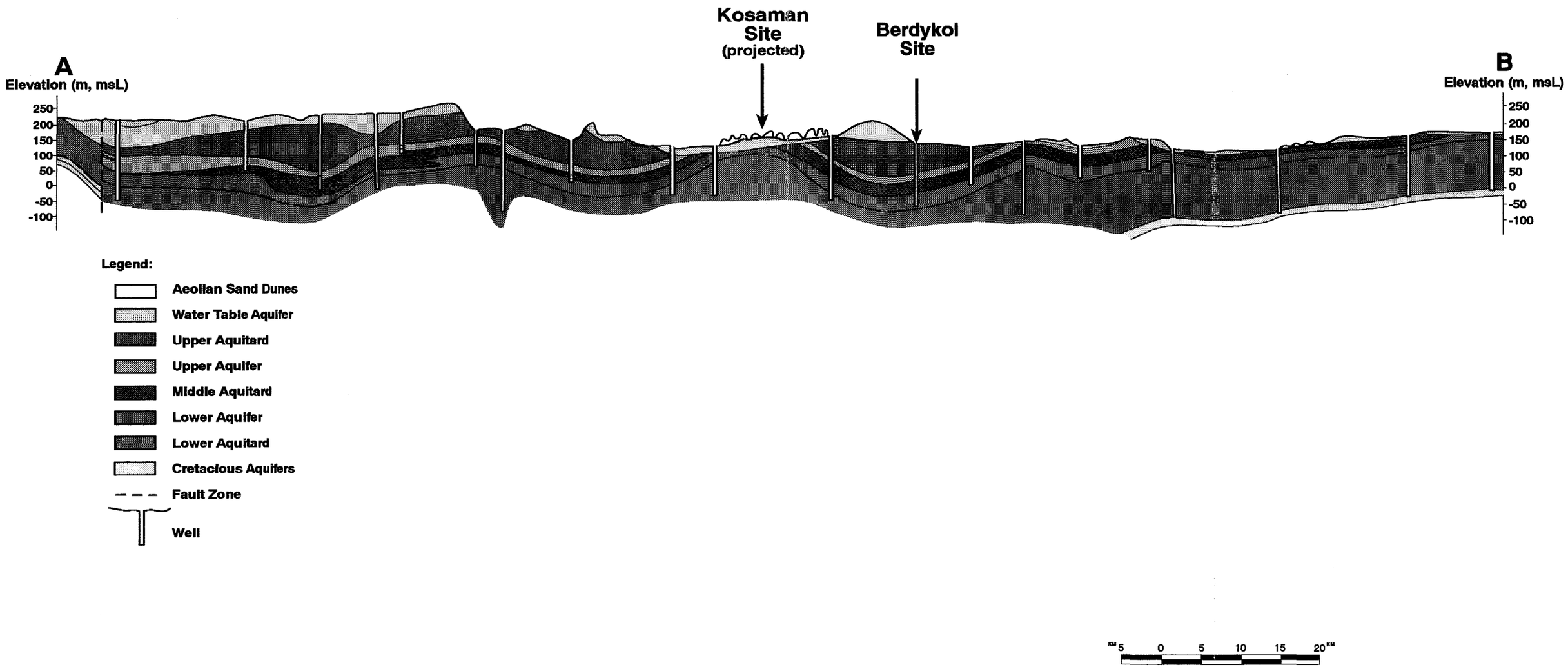
24

m111600.A1.01 Kaza map



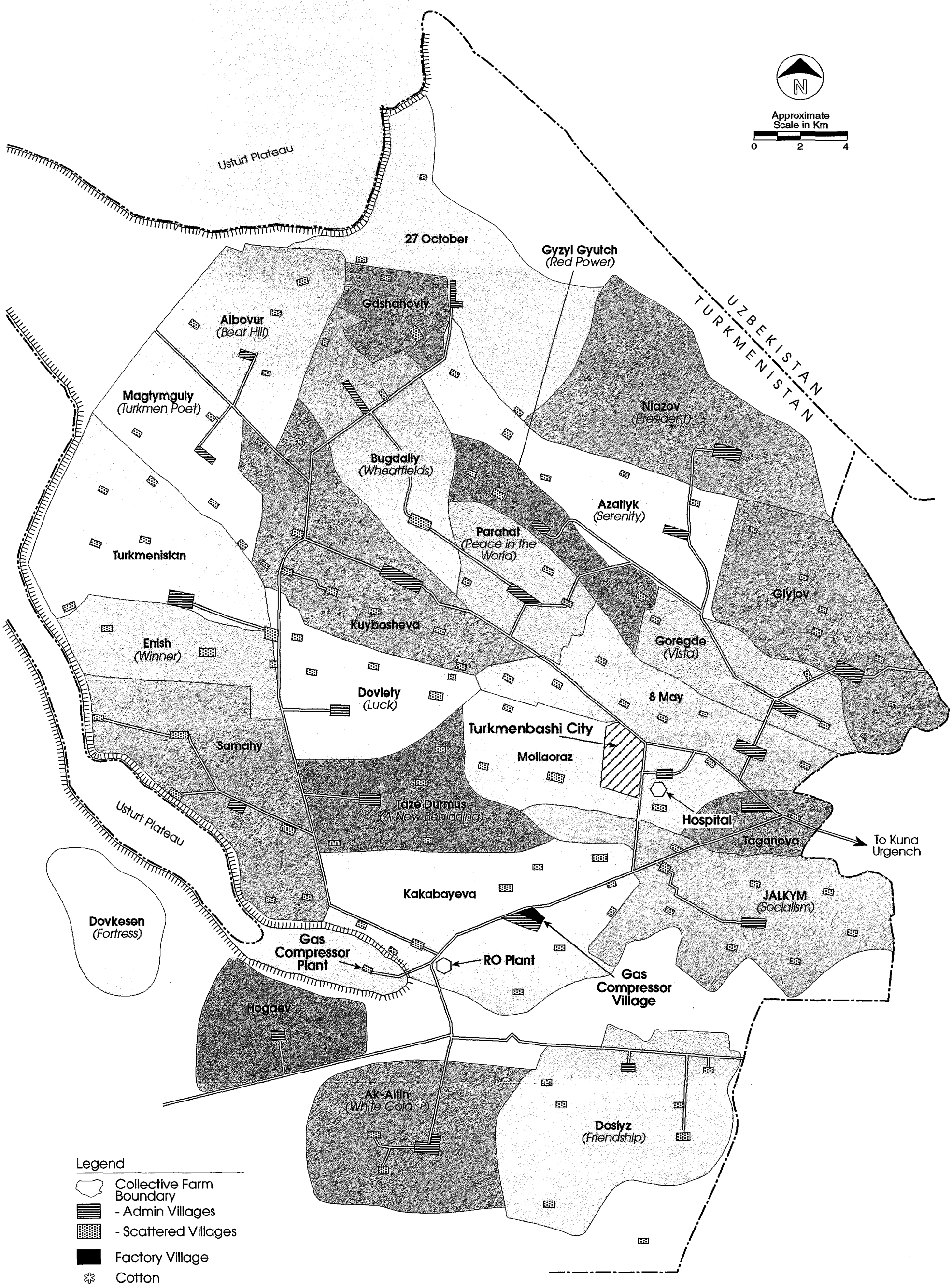
m111600.A1.01 map3 12/95

Figure 3
Generalized Geologic Map



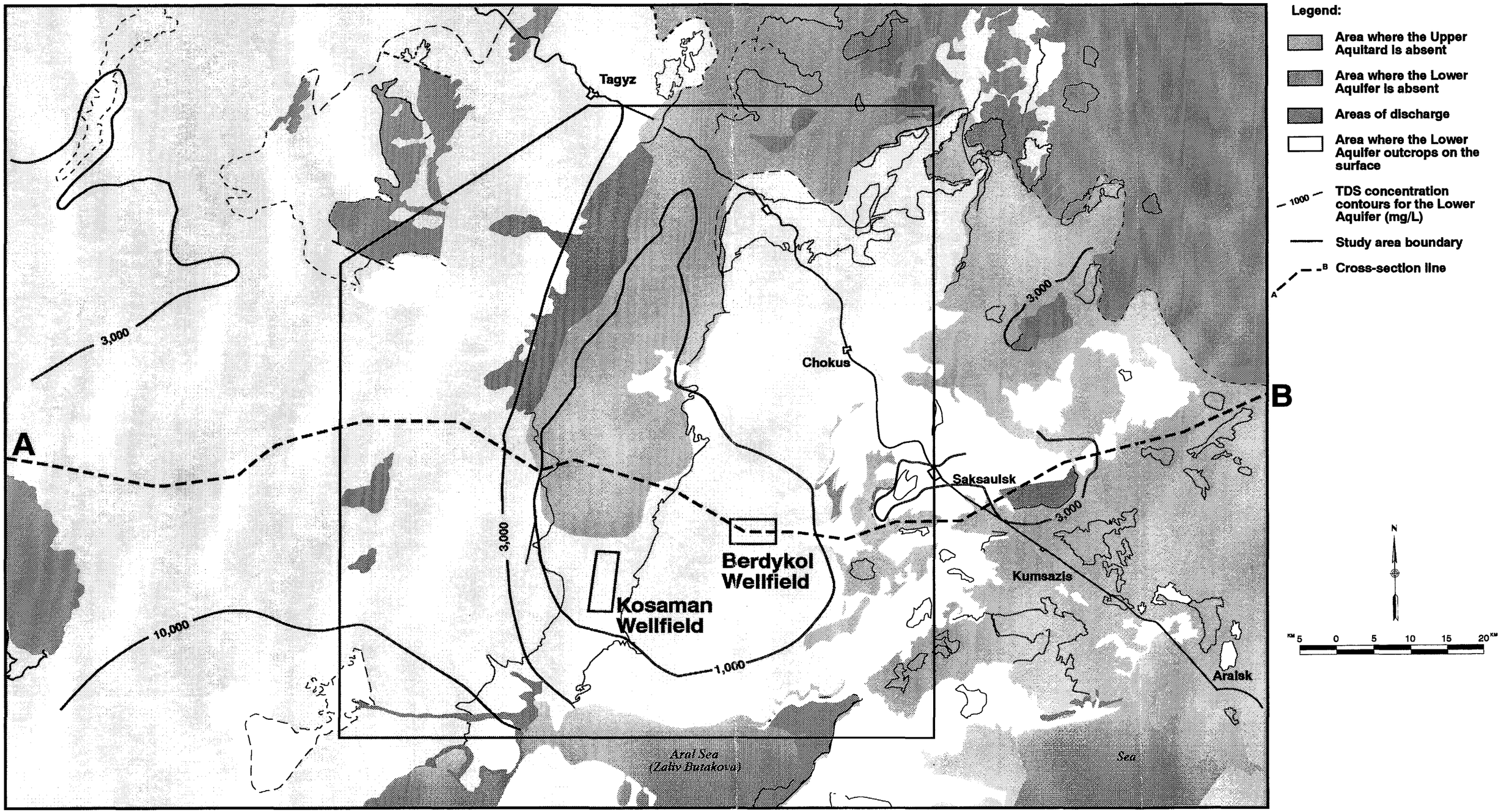
m111600.A1.01/Geo cross sec 12/95

Figure 4
Hydrogeologic Cross-Section



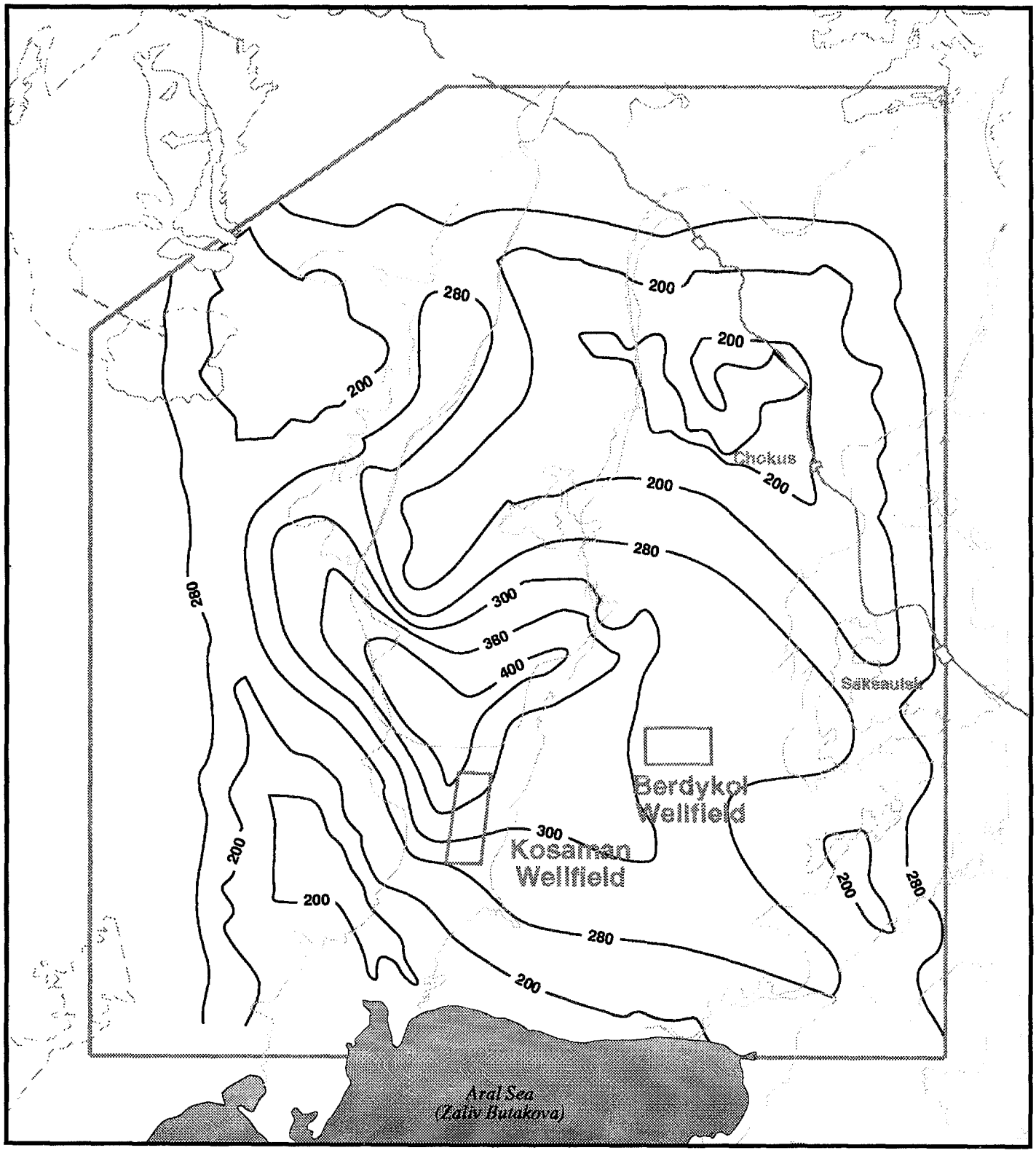
26

FIGURE X. Turkmenbashi Etrap - Collective Farms and Population Centers.



m111600.A1.01 MAP 10/18/95 ach

Figure 5
Hydrogeologic Map of the Study Area



Legend:

— 70 — Transmissivity value (m^2/day)

Study Area Boundary

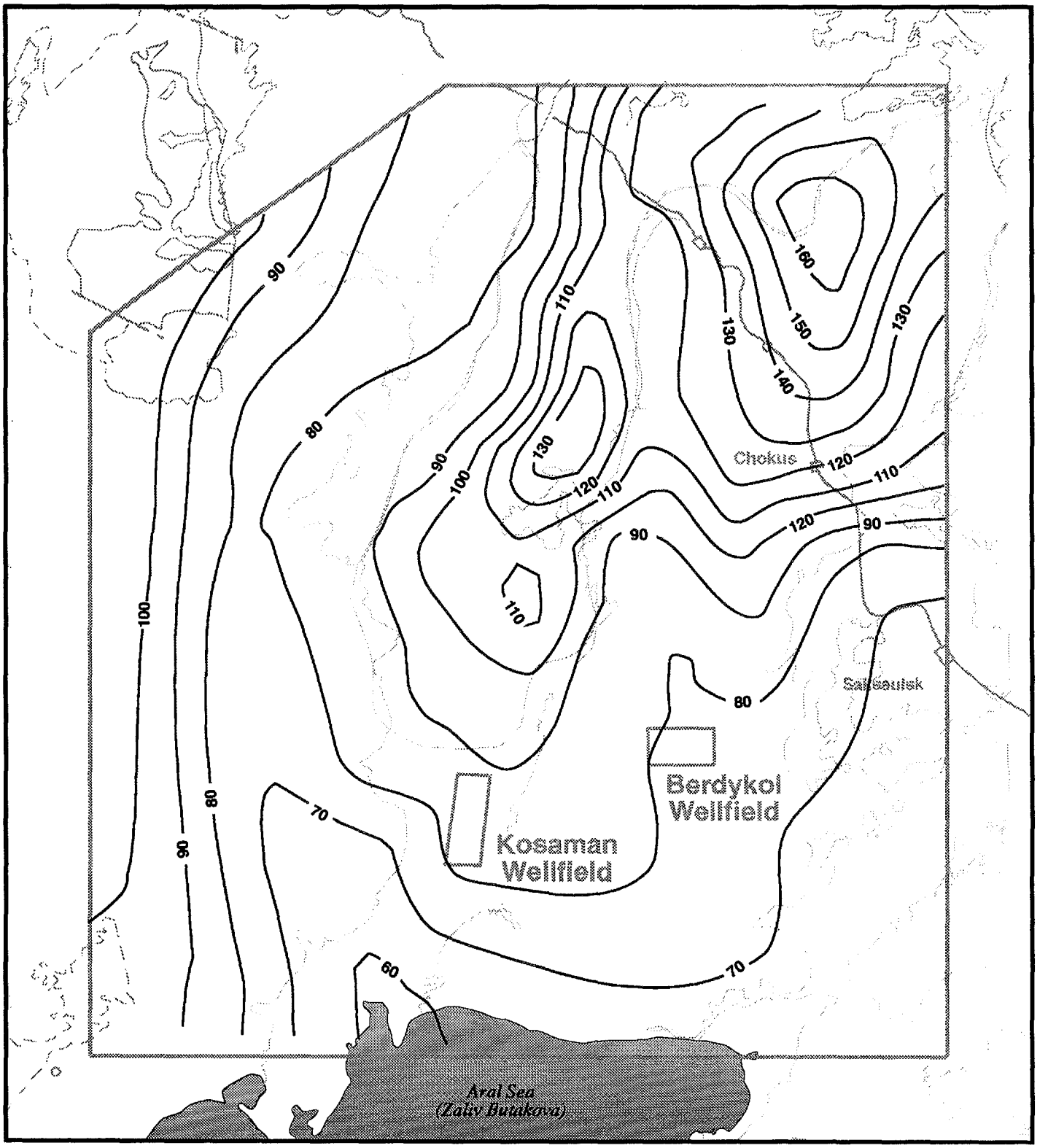
N

KM 5 0 5 10 15 20 KM

Figure 6
Transmissivity Map
Lower Aquifer

28

m111600.a1.01/tms map 12/95 ach



Legend:

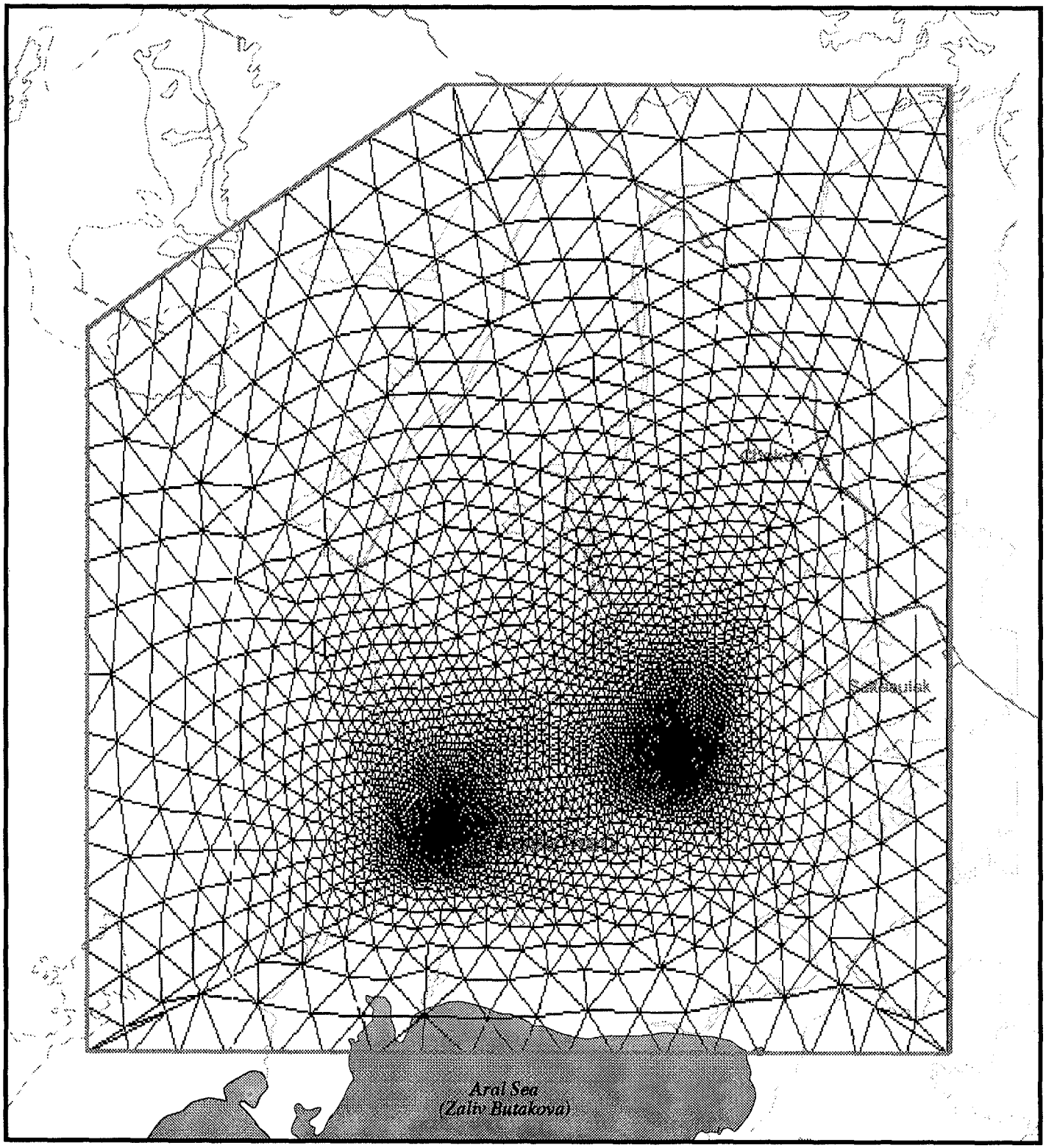
70 — Water Level Elevation Contour (m. msL)

Study Area Boundary

N

KM 5 0 5 10 15 20 KM

Figure 7
Water Level Contour Map for 1971-1975
Upper and Lower Aquifers (undivided)



Legend:

Study Area Boundary

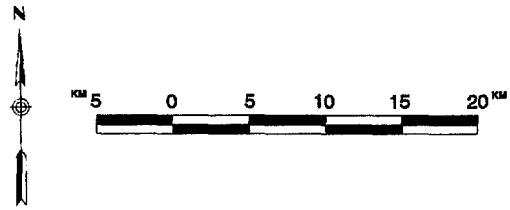
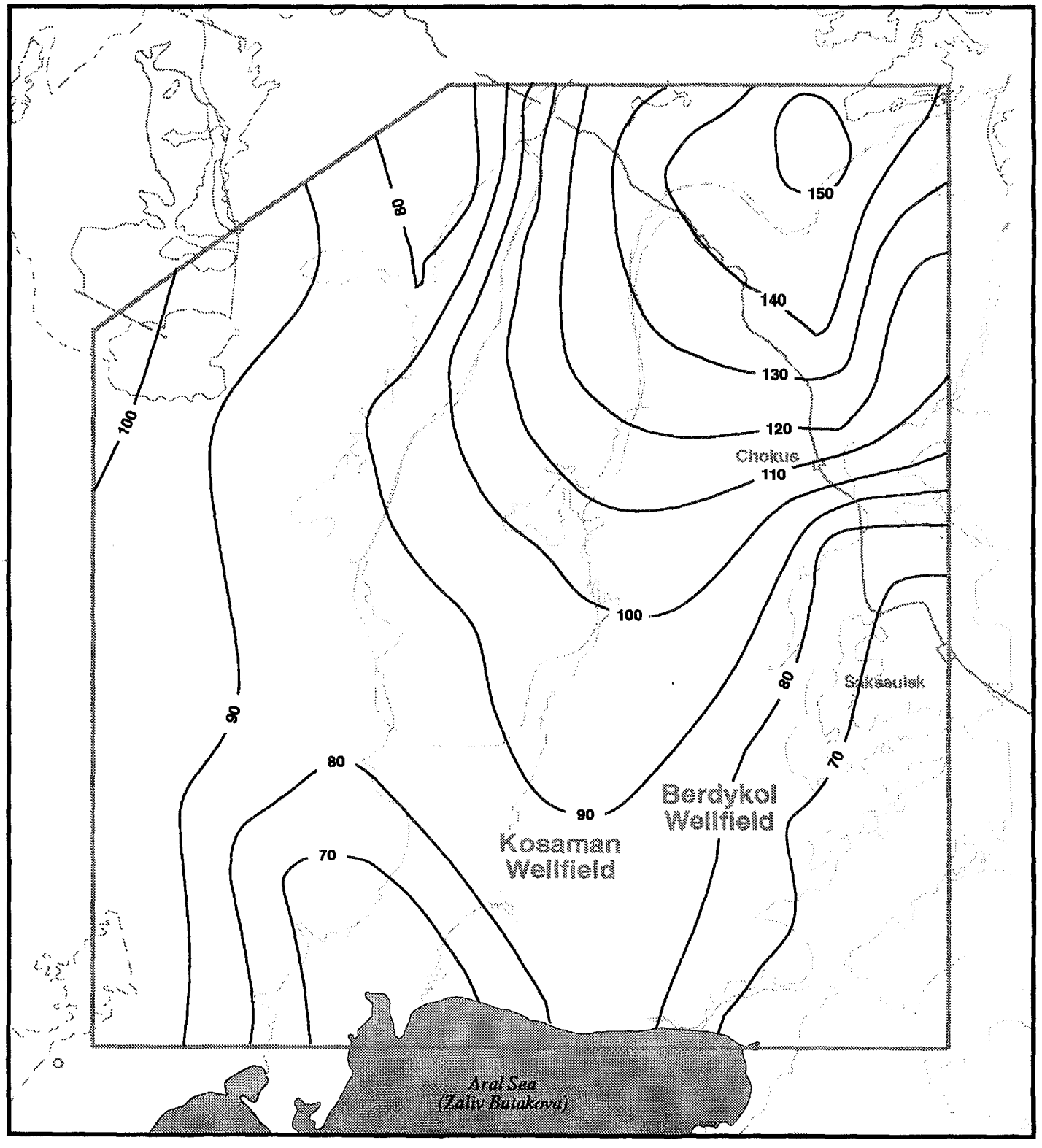


Figure 8
Finite-Element Model Grid

30



Legend:

70 — Water Level Elevation Contour (m msl)

Study Area Boundary

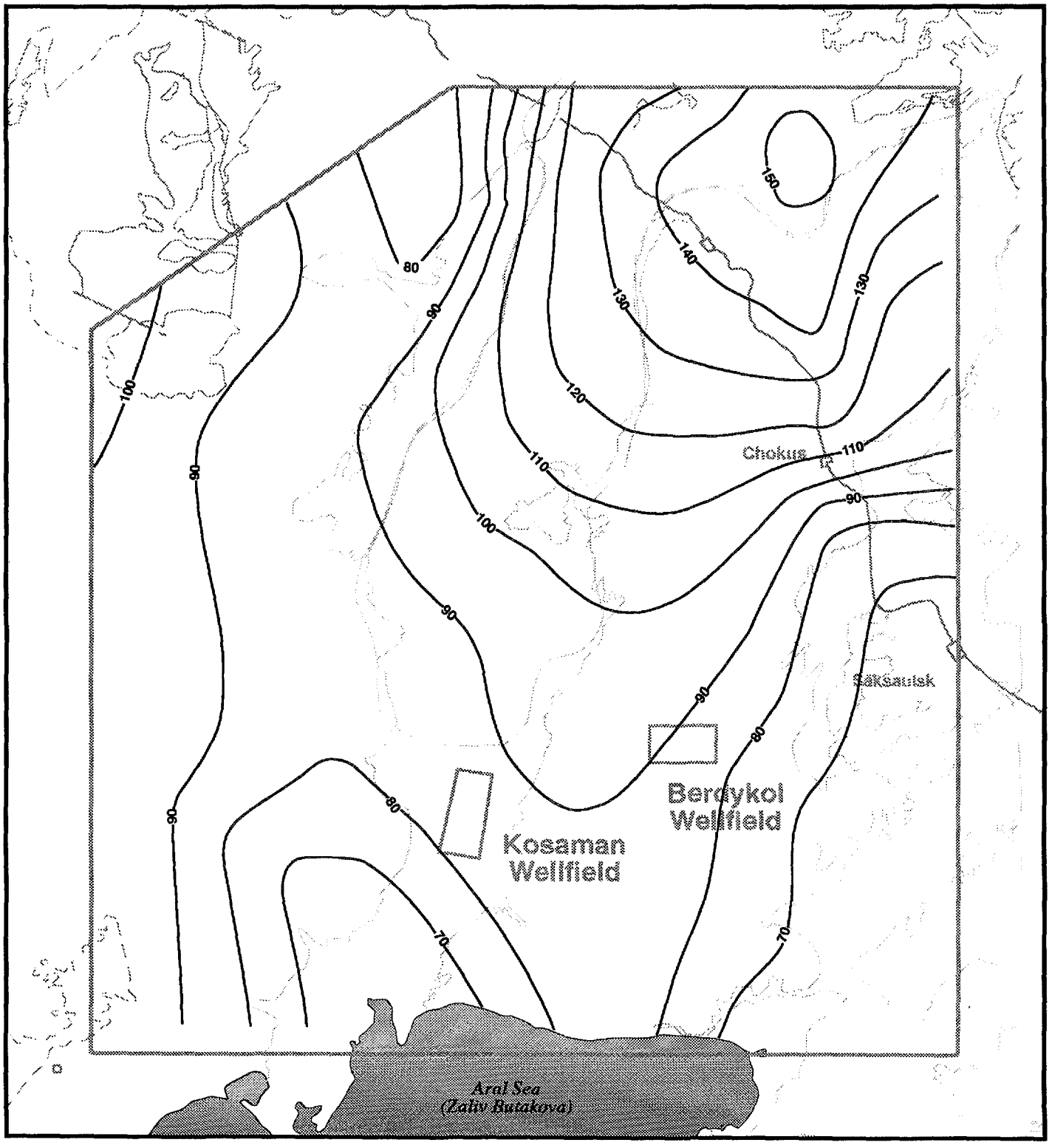
N

KM 5 0 5 10 15 20 KM

Figure 9
Simulated Water Levels
Upper Aquifer
(Calibration Scenario)

m111600.a1.01 fig9 12/95

31



Legend:

70 — Water Level Elevation Contour (m msl)

Study Area Boundary

N

km 5 0 5 10 15 20 km

Figure 10
Simulated Water Levels
Lower Aquifer
(Calibration Scenario)

m111600.a1.01 simwaat 12/95

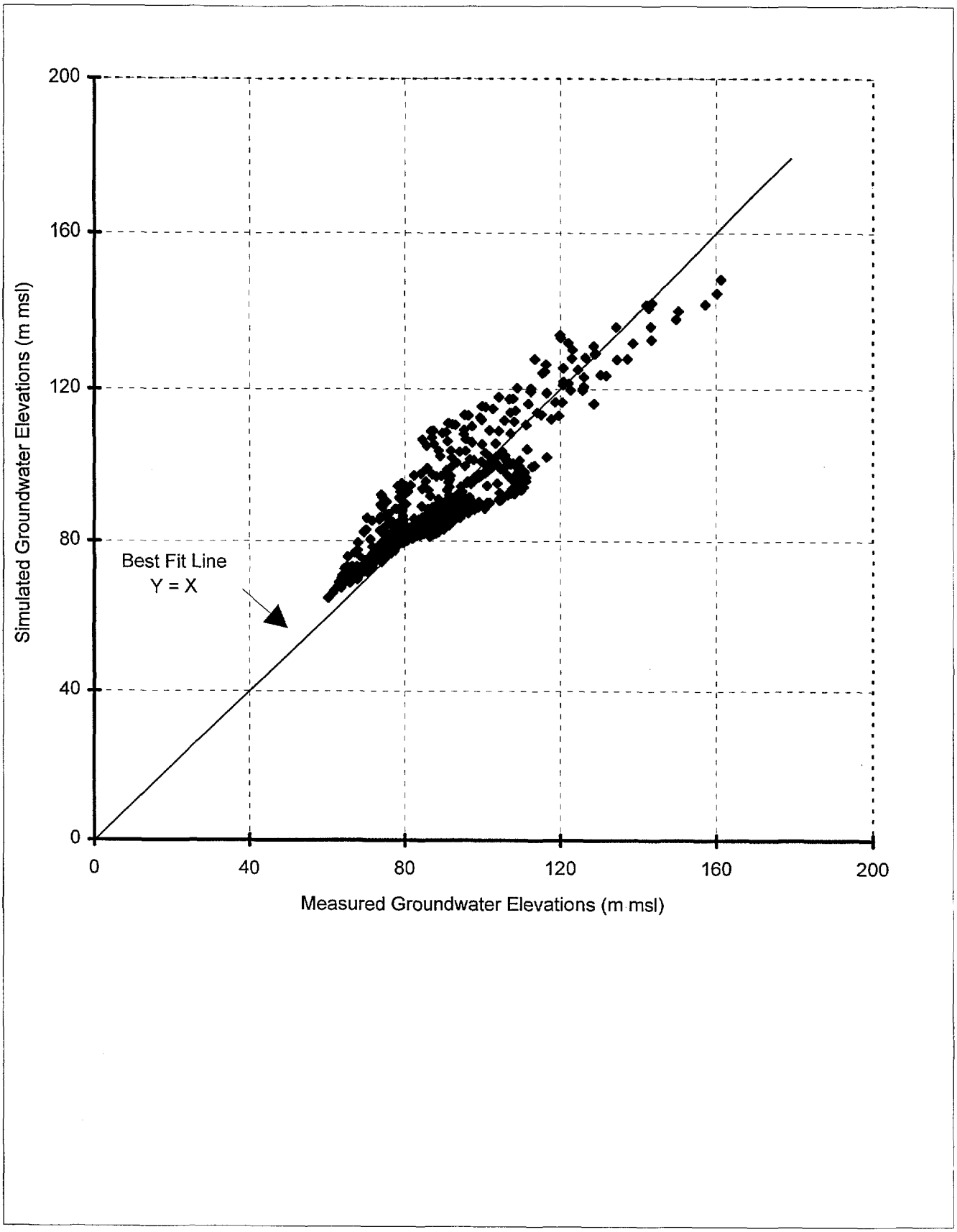
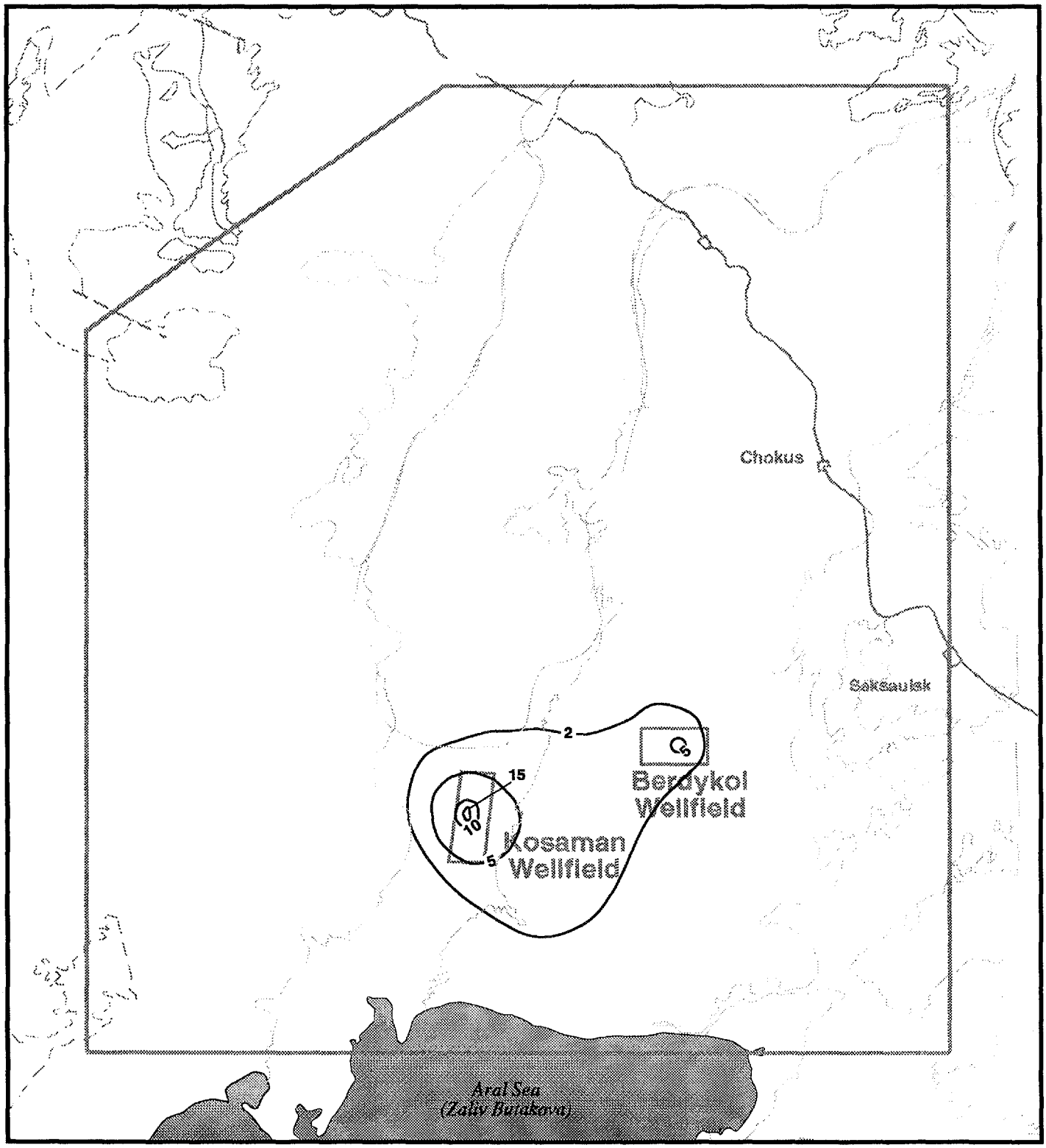


Figure 11
Scatter Diagram of Simulated versus Measured Groundwater Elevations



Legend:

—10— Drawdown contour (m)

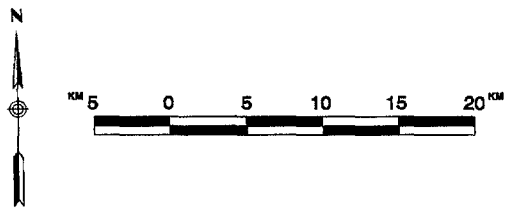
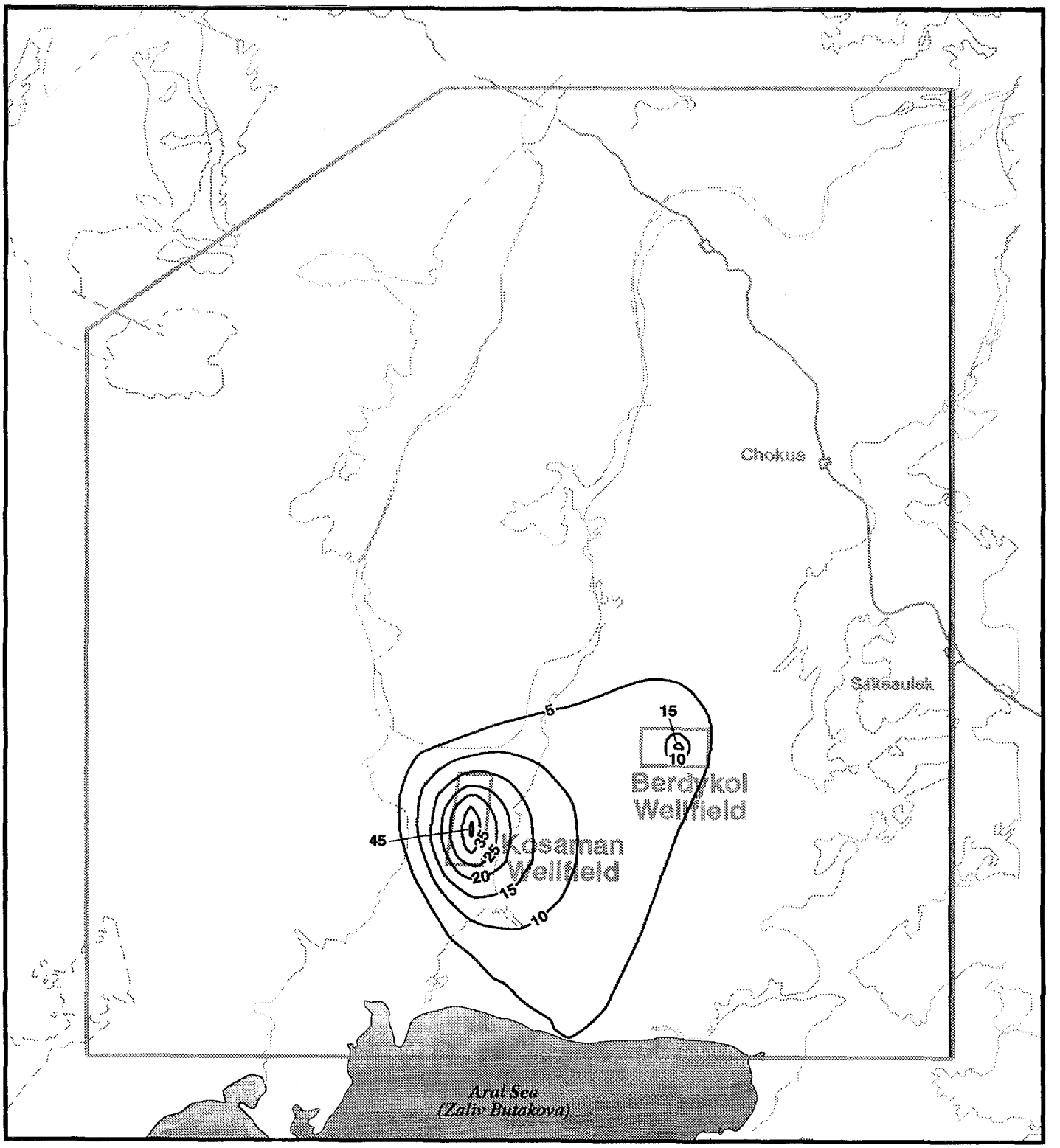


Figure 12
Simulated Drawdowns
Lower Aquifer
(Current Operating Conditions)

34

m111600.A1.01 LOWER AQUIFER 12/95 ach



Legend:

—25— Drawdown contour (m)

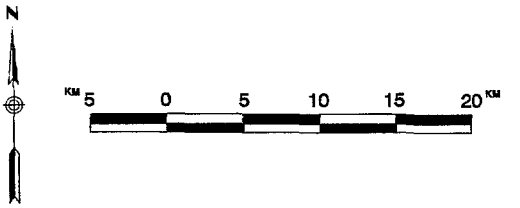
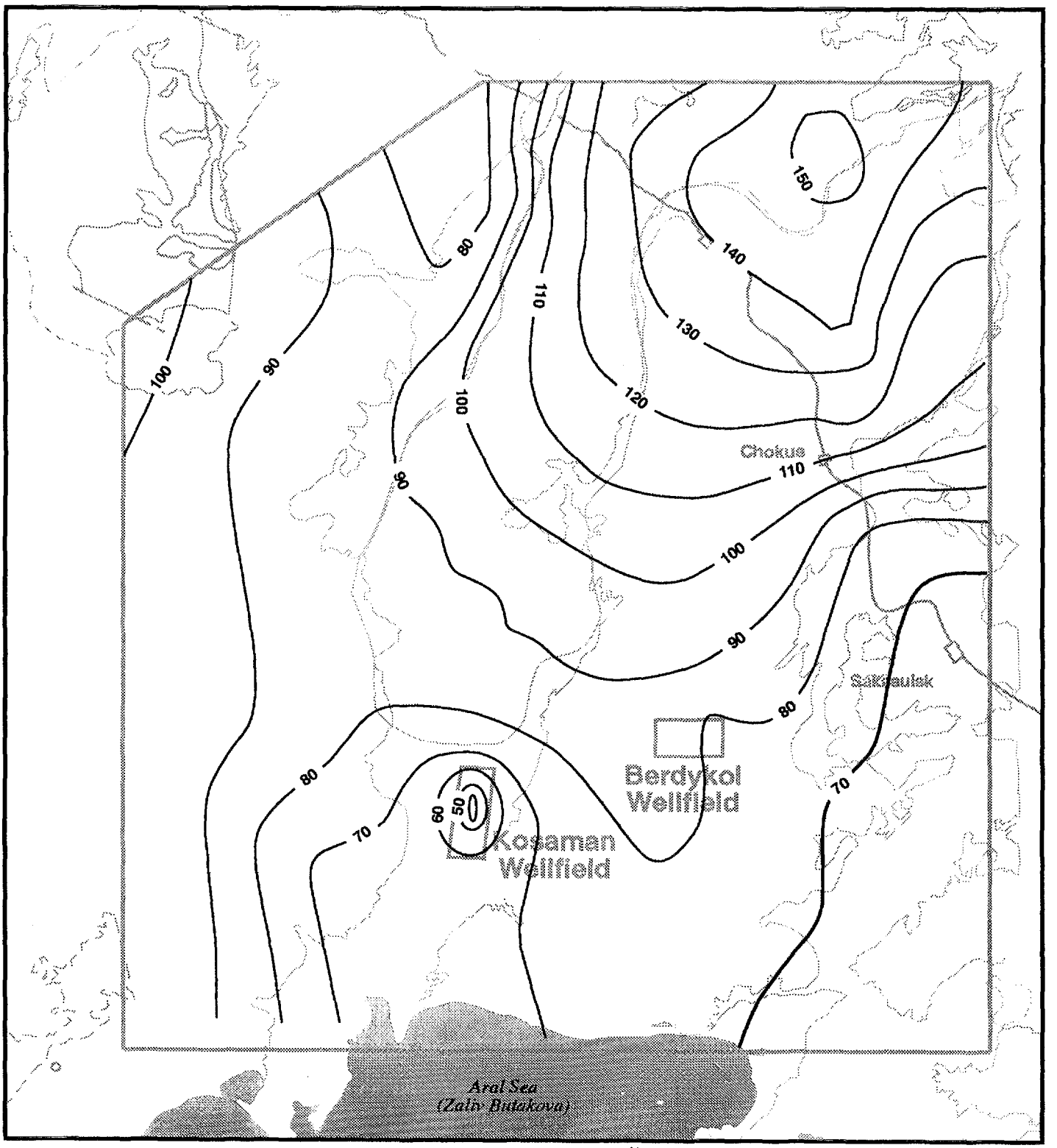


Figure 13
Simulated Drawdowns
Lower Aquifer
(Proposed Operating Conditions)

35

m111600.A1.01 LAsimdraw 12/95



Legend:

70 Water Level Elevation Contour (m. msl)

Study Area Boundary

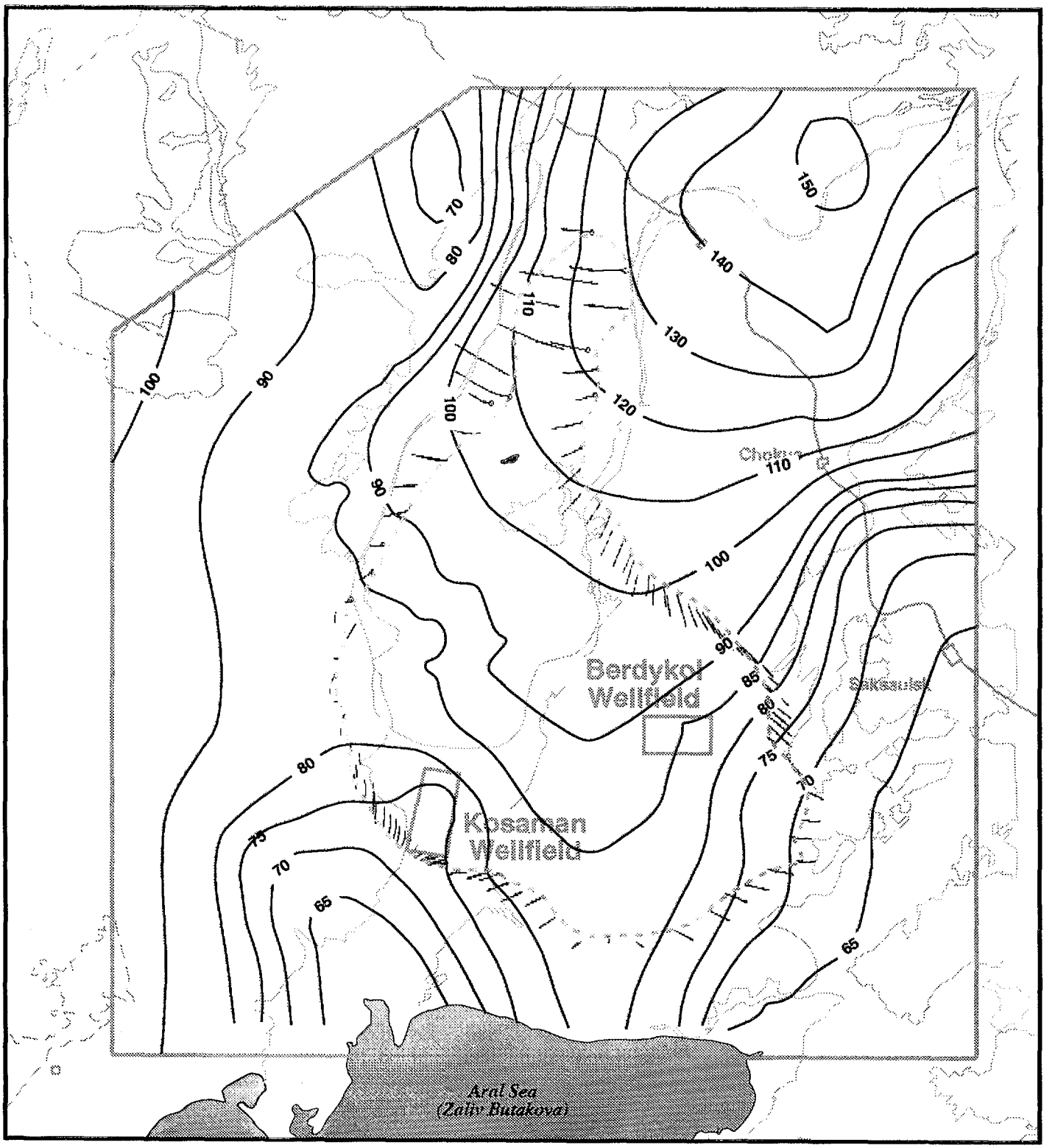
N

KM 5 0 5 10 15 20 KM

Figure 14
Simulated Water Levels
Lower Aquifer
(Proposed Operating Conditions)

36

m111600.a1.01 wtr levels 12/95 ach



Legend:

— 70 — Water Level Elevation Contour (m msl)

Study Area Boundary

Groundwater Pathline

1,000 mg/L TDS Concentration Contour

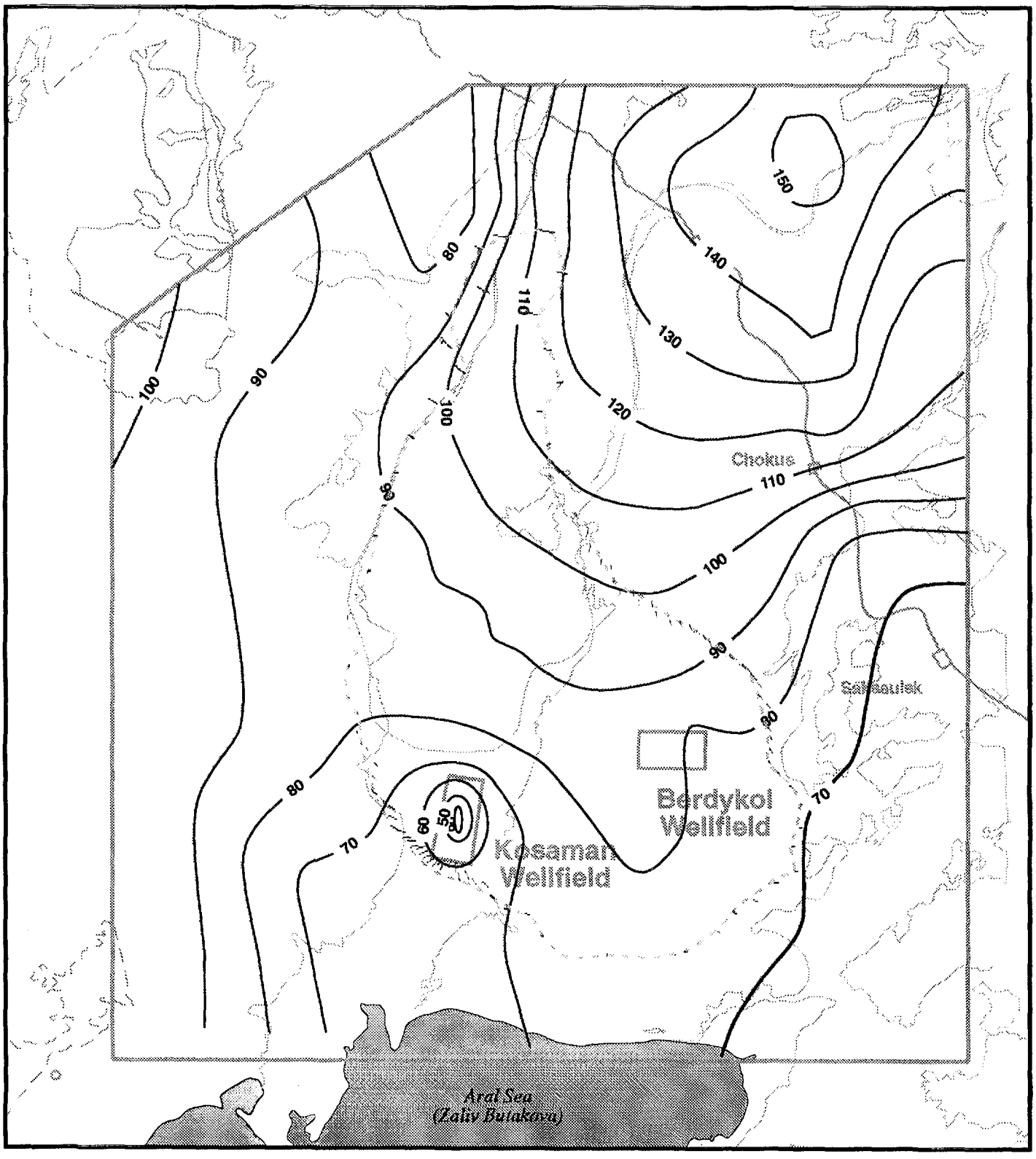
N

KM 5 0 5 10 15 20 KM

Figure 15
Simulated Groundwater Pathlines from 1000 mg/L TDS Concentration Contour After 50 Years
Lower Aquifer
(Current Operating Conditions)

37

m130963.A1.02/fig. 15 12/95vjh



Legend:

- 70 — Water Level Elevation Contour (m msl)
- Study Area Boundary
- Groundwater Pathline
- 1,000 mg/L TDS Concentration Contour

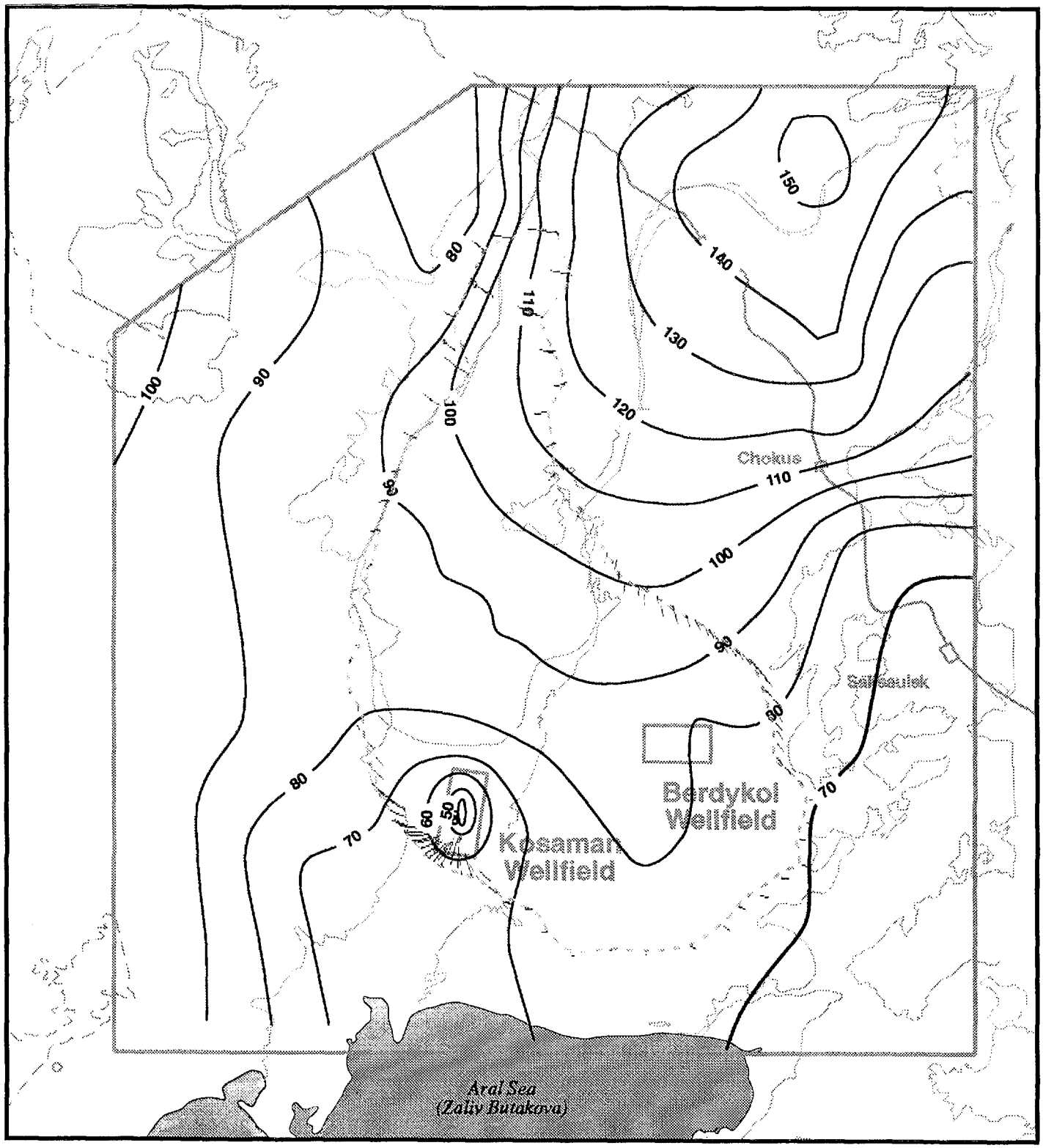
N

KM 5 0 5 10 15 20 KM

Figure 16
Simulated Groundwater Pathlines from 1000 mg/L TDS Concentration Contour After 10 Years
Lower Aquifer
(Proposed Operating Conditions)

m111600.a1.01 FL8 12/95 layer FL8-10

38



Legend:

- 70 — Water Level Elevation Contour (m msl)
- Study Area Boundary
- Groundwater Pathline
- 1,000 mg/L TDS Concentration Contour

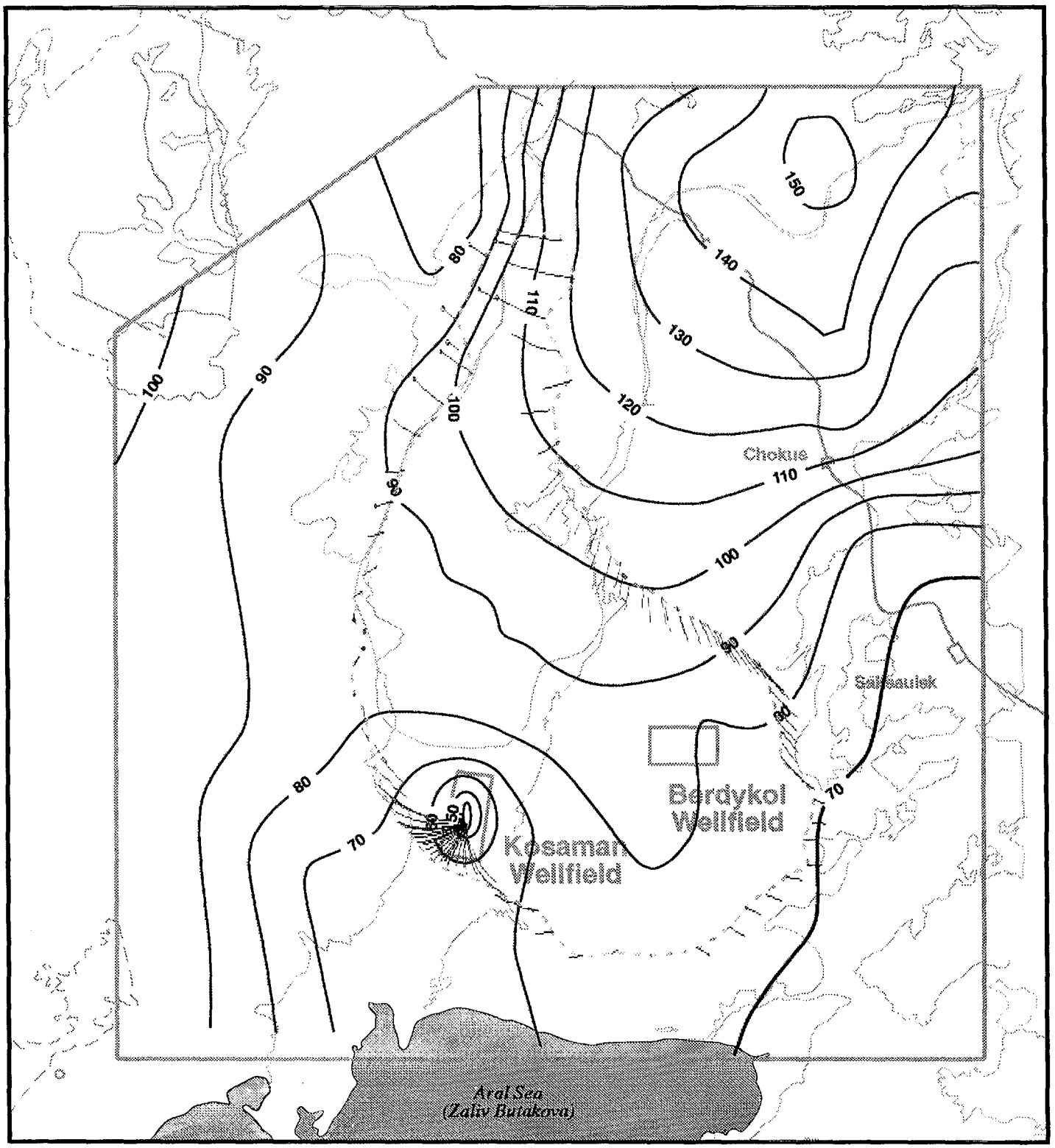
N

KM 5 0 5 10 15 20 KM

Figure 17
Simulated Groundwater Pathlines from 1000 mg/L TDS Concentration Contour After 20 Years
Lower Aquifer
(Proposed Operating Conditions)

38

m111600.a1.01 FL8 12/95 layer FL8_20



Legend:

- 70 — Water Level Elevation Contour (m msl)
- Study Area Boundary
- Groundwater Pathline
- 1,000 mg/L TDS Concentration Contour

N

KM 5 0 5 10 15 20 KM

Figure 18
Simulated Groundwater Pathlines from 1000 mg/L TDS Concentration Contour After 50 Years Lower Aquifer (Proposed Operating Conditions)

m111600.a1.01 FL8 12/95 layer FL8_50

39

Appendix B
Tables

Table 1
Summary of Aquifier Testing Results

Wellfield	Aquifer Test No.	Well No.	Well Type	T sqm/day	S
Kosaman	Test-1	1	OW	384	2.4 E-04
Kosaman	Test-1	2	PW	384	-
Kosaman	Test-1	3	OW	434	2.8 E-04
Kosaman	Test-2	23	OW	409	3.6 E-04
Kosaman	Test-2	24	PW	434	-
Berdykol	Test-1	4	PW	384	-
Berdykol	Test-1	5	OW	353	2.1 E-04

Notes:
T = transmissivity in square meters per day (sqm/day)
S = storativity
AQ = aquifer
OW = observation well
PW = pumping well

Table 2
Conceptual Model of the Tolagaisk Basin

Elevation Meters msL	Geologic Age	Formations	Hydrogeologic Units	Model Layer	Model Properties: Hydraulic Conductivity m/day	Model Properties: Thickness	Model Properties: Anisotropy Ratio kh/kv
80 – 70	Upper Pliocene-Middle Quaternary		Water Table Aquifer	1	8	10	100
60 – 50 – 40 – 30 – 20 – 10 – 0 – -10	Upper Eocene	Alminskiy Formation	Upper Aquitard	2	0.02	80-160	100
-20 – -30 – -40 – -50	Upper Eocene	Upper Bodrukskiy Formation	Upper Aquifer	3	3	30	100
-60 – -70	Upper Eocene	Upper Bodrukskiy Formation	Middle Aquitard	4	0.0086	25	100
-80 – -90 – -100 – -110 – -120	Upper Eocene	Upper Bodrukskiy Formation	Lower Aquifer	5	7-13	30	100
-130 – -140 – -150 – -160	Middle-Upper Eocene	Lower Bodrukskiy Formation	LowerAquitard	6	0.00086	150	100

m111600.A1.01/basin chart 12/95 ach

42

Appendix C
Works Cited

Hemker, C.J., and van Elburg, H. Microcomputer Multilayer Finite Element Groundwater Model. 1988.

Kazakstan Ministry of Geology (MINGEO). Aktyubinsk Expedition, 1976. Water Supply Evaluation in the Tolagaisk Basin based on Investigations Performed 1971-1976.