CHAPTER 12 GROUNDWATER MODELLING

12.1 Groundwater Basin Management and Groundwater Modelling

Groundwater basin management aims at an effective utilization of groundwater that improves the living condition of the people, controls drying-up, contamination and other problems associated with the use of groundwater, and preserves safe environment (Shibasaki et al., 1995). To achieve this aim, it is important to determine the qualitative and quantitative goal of management. Numerical value of quantitative goal is determined based on the concept of permissible yield.

12.1.1 Permissible Yield

1) Permissible Yield and Constraint Factors

The permissible yield can be defined as the “permissible amount of groundwater withdrawal for the residents of the area determined to compare the benefits resulting from the pumpage of groundwater and the risks that might arise from it” (Research Group for Water Balance, 1973).

Factors that determine the permissible yield generally include the following (Shibasaki et al., 1995):

(1) Recharge factor (natural scientific factor): Water balance is maintained.

(2) Economic factor: Cost of pumpage is below a certain level.

(3) Legal factor: No violation of water rights of water laws.

(4) Geo-environmental factor: Not causing dry-up of springs, land subsidence, seawater intrusion, or groundwater contamination.

Geo-environmental factor can be included under economic factor. All the factors above except recharge factor are considered as socio-scientific factors. Though each of these factors is not completely established in the present, it is pragmatic to combine these factors, and determine the permissible yield.

The relative importance of these factors differs depending on the changes in the natural conditions of groundwater or social conditions within communities (Fig. 12.1). The importance of determining factors for permissible yield depends on the circulating velocity, or renewability of the groundwater (Shibasaki et al., 1995). For humid areas with fast circulation and high renewability of the groundwater, the water balance is important and the concept of sustainability is given a priority. On the contrary, for arid regions with a slow circulation and low renewability of the groundwater, the possibility of drying-up is increased, and the economic factor becomes more important.

2) Permissible Critical Groundwater Level

The permissible yield can refer to the groundwater level, which must be retained so that these factors are not violated. In other words, it can be called the permissible critical groundwater level. Groundwater level can be monitored easily by using observation wells and other existing wells. Therefore, if the permissible critical groundwater level is set up, and groundwater level is observed by using a monitoring system, the groundwater pumpage of a basin can be controlled to maintain the permissible yield.

The groundwater modelling is an effective tool to determine the permissible critical groundwater level or the permissible yield, showing an actual example in the following sections.

12.1.2 Work Elements of Groundwater Basin Management

In managing a groundwater basin, the following basic components should be taken into account: Monitoring system, Database, Prediction system, and Decision-making system (Shibasaki et al., 1995) (Fig. 12-2).

1) Monitoring System

Various parameters including groundwater levels, pumpage, groundwater quality should be monitored. Observation wells are used to measure groundwater levels, and their screens must be suitably equipped so that the water level can be measured separately for each aquifer.

2) Database System

A database system is necessary to effectively use and analyze large volume of data and information collected during monitoring. A database system is particularly needed for data on groundwater levels, groundwater withdrawals, and water quality. A database system is also used for geological logs in order to comprehend the structure of a groundwater basin.

3) Prediction System

Based on the findings of monitoring, the conditions of groundwater basin are predicted. The prediction results are used in determining appropriate measures for groundwater utilization. Groundwater modelling (groundwater simulation) is used for prediction. Modelling (Simulation) has been used effectively in predicting the permissible limits of groundwater withdrawal in areas of land subsidence or seawater intrusion in Japan.

It is not sufficient to plan a project by means of predicting once at the beginning of it. Prediction has to be reviewed and repeated every few years, and its accuracy must be enhanced every time.

4) Decision-Making System

Appropriate measures to be taken for groundwater management are determined on the basis of monitoring and prediction. The criterion on which these measures are decided depends upon the concept of permissible yield.

12.2 General Procedure of Groundwater Simulation

The groundwater simulation study is composed of the development of the aquifer model, calibration, prediction and evaluation as shown in Fig. 12-3. An aquifer model is developed with field data manipulated for computer input. After calibrating the model with observed data, prediction of the water level is executed by inputting future abstraction scenario. The predicted results are evaluated for optimum abstraction, taking the water balance, environmental impacts and economics into consideration.

12.2.1 Aquifer Modeling

Aquifer modeling is carried out by numerical groundwater model. The aquifer model simulates a three-dimensional groundwater flow in the phreatic or confined aquifer. The aquifer model is developed by using mainly topography, aquifer distribution, hydraulic characteristics, groundwater discharge and recharge, and groundwater quality.

12.2.2 Data Manipulation

Groundwater model study uses various kinds of input data such as aquifer characteristics, water levels, abstraction, recharge, etc. These data are processed for model inputs.

1) Hydrogeological Data

Hydrogeological data consists of geological and topographical maps, geophysical survey results, composite loggings of test boreholes and pumping tests. Based on these data, contour maps on the surface of aquifer, aquitard and hydrogeological basement are prepared. The contour maps including ground elevation are converted into computer codes. Also, distributions of aquifer characteristics are prepared and converted into computer codes.

2) Water Level

Water levels measured in field are modified to groundwater level elevation based on the ground height of observed points. Then contour maps are converted into computer codes.

3) Groundwater Use and Recharge

Based on the results of the well inventory (Hydrocensus), present groundwater use is estimated. Variation in groundwater use in the past is estimated from the statistical data. Groundwater recharge is estimated by using recharge equations and rainfall data.

12.2.3 Calibration of Model

The model is test-operated by inputting recharge and pumpage data and outputting the calculated groundwater level in each node. The output is compared with the observed water level records, and then the model will be modified/adjusted until final agreement between the calculated and the observed water level is achieved. Thus the model is calibrated and ready to predict water level fluctuations under various abstraction scenarios.

12.2.4 Model Prediction and Evaluation

On the basis of future groundwater abstraction plans, a tentative proposal for groundwater withdrawal plan is prepared. Then the plan is inputted into the calibrated model. The response of the model is evaluated by the following criteria, which should be decided upon the basis of the socio-economic and environmental conditions in the study area:

Evaluation Factor	Criteria
1. Water Balance	Abstraction should be less than the recharge
2. Environmental Impact	Influence to springs and dug wells should be allowable Salinity should be less than the water quality standard
3. Economics	Total pumping head should be less than the criterion

If the model response is not acceptable even for one criterion, then the withdrawal plan should be modified in terms of withdrawal, pumping pattern and borehole location. The model is operated until the final agreement with all the criteria is achieved. With the above steps of aquifer modelling, the optimum abstraction plan (the permissible yield) is fixed and groundwater management plan will be examined.

12.3 Description of Numerical Model

12.3.1 Introduction

It is considered that a model is a tool designed to represent a simplified version of reality, and properly constructed groundwater models, as they are also representations of reality, can be valuable predictive tools for groundwater resources management. Of groundwater models, a mathematical model is commonly used to study groundwater system.

A mathematical model consists of a set of differential equations that describe groundwater flow. Since the assumptions to solve analytically a mathematical model are fairly restrictive, numerical techniques are generally required to solve the mathematical model approximately under realistic situations.

There are many numerical techniques to solve differential equations. Among them, finite difference and finite element methods are representative (Fig. 12-4). The finite difference method is superior in less computer memory requirement and simplicity of data manipulation. The finite element method has excellence in flexibility of mesh formation. In practical aspect of groundwater flow simulation, there is little distinction between both methods. The finite difference method is applied for the proposed groundwater management plan of the study area, in consideration of data availability and accuracy of aquifer parameters.

12.3.2 Groundwater Flow Model

1) Basic Equation of Groundwater Flow

The unsteady-state, three-dimensional movement of groundwater through heterogeneous and anisotropic porous media is described by the following partial-differential equation.

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}\quad(12-1)$$

Where, *Kxx*, *Kyy* and *Kzz*: values of hydraulic conductivity along the *x*, *y* and *z* coordinate axes, *h*: the potentiometric head, *W*: a volumetric flux per unit volume and represents source and/or sink of water, *Ss*: the specific storage of the porous media, *t*: time.

Equation (12-1), together with specified flow and/or head conditions at the boundaries of an aquifer system and specified initial-head conditions, constitutes a mathematical representation of a groundwater flow system. Numerical method, such as the finite difference method, is usually applied to solve equation (12-1).

2) Derivation of the Finite Difference Equation (McDonald and Harbaugh, 1988)

An aquifer system is discretized with a mesh of blocks called “cells” as illustrated in Fig. 12-5, the location of which are referenced with a row(*i*), column(*j*) and layer(*k*) coordinate system parallel to the *x*, *y* and *z* directions, respectively. The width of cells in the row direction, at a given column *j*, is defined $\triangle r_j$; the width of cells in the column direction at a given row *i*, is defined $\triangle c_i$; and the thickness of cells in a given layer *k*, is defined $\triangle v_k$. At center of each cell, there is a point called a “node” at which head is to be calculated.

From the application of the continuity condition, the sum of all flows into and out of the cell is equal to the rate of change in storage within the cell, expressing as follows

$$\Sigma Q_i = \Delta S \quad (12-2)\,.$$

Where, Q_i: flow rate into the cell, $\triangle S$: storage change within the cell over a time interval $\triangle t$. For convenience flow entering cell is defined positive and outflow is defined negative.

A cell *i,j,k* and six adjacent cells are illustrated in Fig. 12-6. Applying finite difference method, groundwater flow is approximated by the node-to-node flow. Flow into cell *i,j,k* in the row direction from cell *i,j-1,k* is given by Darcy's law as

$$Q_{i,j-1/2,k} = KR_{i,j-1/2,k}\Delta c_i \Delta v_k \frac{h_{i,j-1,k} - h_{i,j,k}}{\Delta r_{j-1/2}} \quad (12-3)$$

Where, $Q_{i,j-1/2,k}$: volumetric fluid discharge through the face between cells *i,j,k* and *i,j-1,k*, $h_{i,j,k}$: head at node *i,j,k*, $h_{i,j-1,k}$: head at node *i,j-1,k*, $KR_{i,j-1/2,k}$: hydraulic conductivity along the row between nodes *i,j,k* and *i,j-1,k*, $\triangle c_j \triangle v_k$: area of the cell faces normal to the row direction, $\triangle r_{j-1/2}$: distance between nodes *i,j,k* and *i,j-1,k*. The hydraulic conductivity between the nodes is normally calculated as a harmonic mean.

$$KR_{i,j-1/2,k} = \frac{2KR_{i,j-1,k}KR_{i,j,k}}{KR_{i,j-1,k} + KR_{i,j,k}} \quad (12-4)$$

Similar expressions can be written approximating the flow into the cell through the remaining five faces. Flow in row direction through the face between cells *i,j,k* and *i,j+1,k* is expressed as

$$Q_{i,j+1/2,k} = KR_{i,j+1/2,k}\Delta c_i \Delta v_k \frac{h_{i,j+1,k} - h_{i,j,k}}{\Delta r_{j+1/2}} \quad (12-5)$$

While for the column direction, flow into the cell through the forward face is

$$Q_{i+1/2,j,k} = KC_{i+1/2,j,k}\Delta r_j \Delta v_k \frac{h_{i+1,j,k} - h_{i,j,k}}{\Delta c_{i+1/2}} \quad (12-6)$$

And flow into the cell through the rear face is

$$Q_{i-1/2,j,k} = KC_{i-1/2,j,k}\Delta r_j \Delta v_k \frac{h_{i-1,j,k} - h_{i,j,k}}{\Delta c_{i-1/2}} \quad (12-7)$$

For the vertical direction, inflow through the bottom face is

$$Q_{i,j,k+1/2} = KV_{i,j,k+1/2} \Delta r_j \Delta c_i \frac{h_{i,j,k+1} - h_{i,j,k}}{\Delta v_{k+1/2}} \quad (12-8)$$

While inflow through the upper face is given by

$$Q_{i,j,k-1/2} = KV_{i,j,k-1/2} \Delta r_j \Delta c_i \frac{h_{i,j,k-1} - h_{i,j,k}}{\Delta v_{k-1/2}} \quad (12-9)$$

The notation can be simplified by combining grid dimensions and hydraulic conductivity into a single constant ("hydraulic conductance"). Hydraulic conductance between nodes *i,j-1,k* and *i,j,k* can be written as

$$CR_{i,j-1/2,k} = KR_{i,j-1/2,k} \frac{\Delta c_i \Delta v_k}{\Delta r_{j-1/2}} \quad (12-10)$$

Storage change within the cell over a time interval $\triangle t$ is expressed as follows.

$$\Delta S = Ss_{i,j,k} \frac{\Delta h_{i,j,k}}{\Delta t} \Delta r_j \Delta c_i \Delta v_k \quad (12-11)$$

Where, $Ss_{i,j,k}$: specific storage of cell *i,j,k*, $\triangle h_{i,j,k}$: head change over a time interval $\triangle t$, $\triangle r_j \triangle c_i \triangle v_k$: volume of cell *i,j,k*. Assuming $\triangle t = t_m - t_{m-1}$, an approximation to the time derivative of head at time t_m can be written as

$$\left(\frac{\Delta h_{i,j,k}}{\Delta t} \right)_m = \frac{h^m_{i,j,k} - h^{m-1}_{i,j,k}}{t_m - t_{m-1}} \quad (12-12)$$

Where, $h^m_{i,j,k}$: head of cell *i,j,k* at time t_m, $h^{m-1}_{i,j,k}$: head of cell *i,j,k* at time t_{m-1} which precedes t_m.

Substituting equation (12-3), equations (12-5) through (12-9), and equations (12-11) and (12-12) into equation (12-2), and applying relationship in equation (12-10), finite difference approximation for cell *i,j,k* can be obtained as

$$\begin{aligned}
&CR_{i,j-1/2,k}\left(h^m_{i,j-1,k} - h^m_{i,j,k}\right) + CR_{i,j+1/2,k}\left(h^m_{i,j+1,k} - h^m_{i,j,k}\right) + \\
&CC_{i-1/2,j,k}\left(h^m_{i-1,j,k} - h^m_{i,j,k}\right) + CC_{i+1/2,j,k}\left(h^m_{i+1,j,k} - h^m_{i,j,k}\right) + \\
&CV_{i,j,k-1/2}\left(h^m_{i,j,k-1} - h^m_{i,j,k}\right) + CV_{i,j,k+1/2}\left(h^m_{i,j,k+1} - h^m_{i,j,k}\right) + OS_{i,j,k} \\
&= Ss_{i,j,k}\left(\Delta r_j \Delta c_i \Delta v_k\right) \frac{h^m_{i,j,k} - h^{m-1}_{i,j,k}}{t_m - t_{m-1}} \quad (12-13)
\end{aligned}$$

Where, $QS_{i,j,k}$: source or sink term of cell *i,j,k*.

An equation of this form is written for every cell in the calculation domain, and the system of equations is solved simultaneously for the heads at time t_m. Solving techniques of simultaneous equations are classified into direct and iterative methods. Finite difference approximation of three-dimensional groundwater flow produces a large system of simultaneous equations. Iterative method is superior to direct method in requirement of computer memory, and is usually used to solve such large system. Strongly Implicit Procedure method (SIP), Slice Successive Overrelaxation method (SSOR), and Preconditioned Conjugate Gradient method (PCG) are typical of iterative method. Precise explanation of solving techniques should be referred to McDonald and Harbaugh (1988), and Hill (1990).

3) MODFLOW

MODFLOW (Modular Finite-Difference Ground-Water Flow Model) developed by U.S. Geological Survey (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996), is widely used numerical model which can simulate groundwater flow in a three-dimensional heterogeneous and anisotropic medium. As mentioned in the following section, MODFLOW was applied to simulate groundwater flow systems in the Stampriet Artesian Basin.

In a three-dimensional finite difference model, vertical discretization can be seen as a sequence of horizontal layers. In complicated hydrogeological condition, this grid system causes a cell contain material from different stratigraphic units (Fig. 12-7(b)). In MODFLOW, vertical discretization can be viewed as an effort to represent individual aquifers or permeable zones by individual layers of the model (Fig. 12-7(c)). This distortion can be generated by giving the elevation of the top and bottom of the layer. It allows flexibility in discretizing, however, introduces small error into the finite difference approximation.

12.4 Conceptual Model

12.4.1 Hydrogeologic Condition

From a geological point of view, there are major four formations. They are the Damara Sequence, the Nama Group, the Karoo Sequence and the Kalahari Beds. The relationships among four formations are unconformity. The Damara Sequence and the Nama Group consist of sandstone, shale and metamorphic rocks. They form the hydrogeological basement. The Karoo Sequence is divided into the Dwyka Group and the Ecca Group. The Dwyka Group is composed of tillite and mudstone, and is also a hydrogeological basement. The Ecca Group is divided into the Nossob, Mukorob, Auob and the Rietmond Members. The Nossob Member is composed of sandstone and is a confined aquifer. The Lower Mukorob Member consists of shale and is an aquitard/ aquiclude. The Upper Mukorob Member consists of sandstone and is a confined aquifer. The Auob Member is composed of sandstone and shale. It contains three confined aquifers and two aquitards. However, it is difficult to clarify the distribution of these aquifers and aquitards over the whole study area. Therefore, the Auob Member is assumed to be one confined aquifer. The Lower Rietmond Member is composed of shale, and is an aquitard. The Upper Rietmond Member consists of sandstone, and is an unconfined or confined aquifer. The Kalkrand Basalt and the Karoo Dolerite intrude into the Auob and Rietmond Members and are considered to be an unconfined-confined aquifer or aquitard. The Kalahari Beds are composed of sand, gravel and calcrete. It is an unconfined aquifer. Between the Kalahari Beds and the Upper Rietmond Member, there is no distinct aquitard or low-permeability layer.

12.4.2 Aquifer System

As a result of the above discussion, an aquifer system consisting of one unconfined aquifer and two confined aquifers with two confining layers (aquitards) was selected for the groundwater model in the Stampriet Artesian Basin. The unconfined aquifer represents the Kalahari and the Upper Rietmond aquifers. The first confined aquifer represents the Auob and the Upper Mokorob aquifers. The second confined aquifer represents the Nossob aquifer. The upper unconfined aquifer and the first confined aquifer are connected due to leakage through the first confining layer (the Lower Rietmond Member). The first confining layer is absent and the unconfined aquifer directly overlies the first confined aquifer with a large area of the Stampriet Basin. In that area, the lower part of the unconfined aquifer is assumed to be an aquitard. The second confined aquifer is considered to be isolated from upper aquifers (Table 12-1).

12.5 Data Manipulation

12.5.1 Grid Design

Considering the hydrogeological structure of the study area, modeled domains were defined as shown in Fig. 12-8. The model area covers all of the Stampriet Artesian Basin. The area of the domain is about 125,000 km^2 (303×413km). The domain was divided by a grid at intervals of 6.3 km in the longitudinal and 6.9km in the latitudinal directions (see Fig. 12-9). Numbers of cells in row and column directions are 60 and 48 respectively. The application of a fixed grid system causes a slight error in the cell size, but it is negligible in practical application of the model (see Fig. 12-10).

12.5.2 Elevation of Top and Bottom of Layers

As mentioned previously, a deformed grid can be used in MODFLOW. Therefore, the study area was divided into 6 layers in vertical direction, and the elevations of the top and bottom of layers were given. The Model layers basically correspond to the Kalahari Beds, the Upper Rietmond Member, the Lower Rietmond Member, the Auob Aquifer, the Lower Mukorob Member, and the Nossob Aquifer. However, individual aquifers or aquitard cannot be represented by individual layers of the model, because of the complicated hydrogeological condition of the study area. The elevations of the top and bottom of layers were determined according to the following procedure.

1) Digitization of Isodepth and Isopach Maps

The isodepth and isopach maps shown in Section 8.3 were digitised for each cell;

- Surface Elevation
- Bottom of Kalahari Beds (Fig. 8.3-2)
- Isopach of Lower Rietmond Member (Fig. 8.3-3)
- Top of Auob Aquifer (Fig. 8.3-4)
- Isopach of Auob Aquifer (Fig. 8.3-5)
- Isopach of Lower Mukorob Member (Fig. 8.3-6)
- Isopach of Nossob Aquifer (Fig. 8.3-8)

Also, averaged value of “USGS Satellite 30 seconds Elevation Data” was used for the surface elevation of each cell.

The difference between the surface elevation and the bottom of the Kalahari Beds was assumed to be the thickness of the Kalahari Beds. If the value of bottom of the Kalahari Beds was higher than the surface elevation, it was revised to be lower than the surface (5 to 10 meters in thickness). In the area where the Kalahari Beds directly overlay the Auob Aquifer, the top of the Auob Aquifer was revised to be the same as the bottom of the Kalahari Beds.

The value obtained through subtracting the top of the Auob Aquifer from the bottom of the Kalahari Beds was assumed to be the thickness of the Rietmond Member. The thickness of the Upper Rietmond Member was calculated to subtract the thickness of the Lower Rietmond Member from that of the Rietmond Member.

The bottom of the Auob Aquifer was obtained to subtract the thickness of the Auob Aquifer from the top of it. The bottom of the Lower Mukorob Member was calculated to subtract the thickness of it from the bottom of the Auob Aquifer. Then, the bottom of the Nossob Aquifer was calculated to subtract the thickness of it from the bottom of the

Lower Mokorob Member successively.

Digitized isodepth and isopach maps of aquifers and aquitards. These digitized isodepth maps were used for summing up groundwater use by aquifer.

2) Elevation of Model Layers

The abovementioned aquifers and aquitards do not sequentially lie on top of another, since the hydrogeological condition of the study area is complex. There are 22 combinations of overlaying of them as shown in Table 12-2. The combination of each cell is shown in Table 12-3.

Allotment of aquifers and aquitards to the model layers was executed according to the procedure given in Table 12-4. The bottom elevations of layers are shown in Table 12-5 to Table 12-10. Fig. 12-11 shows the N-S cross-sectional grid design at column 25. Fig. 12-12 shows the E-W cross-section at row 30 (Locations of sections are shown in Fig. 12-8).

12.5.3 Boundary Condition

The model area is bounded by basement rocks on the north. However, the Kalahari Beds overlying basement rocks continue to the outside of the study area. Groundwater inflow can be expected across the border. Therefore, constant head condition was assumed at this boundary to approximate the groundwater inflow. On the western side, the distribution of the first and second confined aquifers is restricted at the border. This boundary was considered as a no flux condition. Near Kalkrand, groundwater level contours show outflow from the study area, therefore discharging condition was set on this border. On the southern border, the model area is bounded by basement rocks. No flux boundary condition was assumed. On the eastern side, the aquifers are continuous to the territory of Botswana and South Africa. Since groundwater level contours are almost perpendicular to the boundary, it was considered to be no flux condition. On the right bottom corner of the model, groundwater outflow can be expected across the border through the Kalahari Beds. Constant head condition was assumed to approximate the groundwater outflow.

The boundary conditions of the modelled area are shown in Fig. 12-8.

12.5.4 Aquifer Constants

There are very few pumping test data, excluding the JICA test boreholes as mentioned in section 2.5. Distributions of the permeability of aquifers are shown in Figs. 12-13 to

12-15. The study area was divided into several zones based on these figures. The permeability of a zone is assumed to be homogeneous and isotropic. These values were modified in the process of model calibration.

All pumping tests, except one, were executed without observation boreholes, therefore accurate storativity values were not able to obtain. The storativity values of the aquifers set uniformly and then these values modified in the model calibration process.

12.5.5 Groundwater Levels

The groundwater levels have been measured in the water level survey (section 2.8). The elevation survey of boreholes has been also done (section 2.7). Based on the results of these surveys, groundwater level contour maps were drawn. These maps were used in the model calibration.

There are 22 observation boreholes of the DWA. At these boreholes groundwater level changes have been measured monthly. Also, groundwater levels have been observed monthly in 30 NamWater boreholes. Observed groundwater level changes were used in the model calibration.

12.5.6 Pumpage

1) Data Source and Estimation Method

Data source and estimation method of present groundwater use is shown in Table 12-11. Production rate of NamWater is monthly, and report of irrigation permit holders is also monthly. The results of the Hydrocensus are average values at the surveyed date.

If the number of people in a farm was unknown, it was estimated by using farm area and unit population. Also, number of stocks was estimated from farm area and carrying capacity, if it was unknown. Average value of the Hydrocensus is used in the ratio of small stocks and large stocks.

Information of farms, which have not been surveyed by the Hydrocensus, is only farm area in the DWA database. The number of people and stock was estimated in the same way as mentioned above.

2) Results of the Hydrocensus

Present groundwater use was estimated, mainly based on the results of the Hydrocensus. The results are summarized in Table 12-12.

3) Summary of NamWater Scheme

Production rates of NamWater scheme are summarized in Table 12-13, and variations of each scheme are shown in Fig. 12-16. Monthly production rates of each scheme are given in Appendix Table B-1 to B-28.

Total production increased from 482 thousand m^3/year in 1986 to 604 thousand m^3/year in 1999. The production of the Aranos scheme is largest and about 40% of total in 1999.

4) Summary of Irrigation Permits

The irrigation permits are valid for five years, and water allocation is prescribed in annual production per farm. Boreholes must be equipped with water gauges, but some are not equipped. Monthly productions should be reported, however the DWA records on each farm are incomplete.

Using values of same month in the previous year or in the following year, lacking records of the monthly production reports were estimated. The results are shown in Table 12-14.

Irrigation uses of the permit holders have a tendency to increase. However, it is 64% of the allocated amount in 1999. The relation to rainfall is not distinct. The production in 1997 with a lot of rain is smaller than those in 1996 and 1998 with little rainfalls. But, the production in 1995 is smaller than that in 1996, although the rainfall in 1995 is less than that in 1996 (Fig. 12-17). Also, the relationship between monthly production and monthly rain is not clear (Fig. 12-18).

The groundwater abstraction for irrigation use affects the groundwater level change. For example, the water level change of the Spes Bona observation borehole (WW32457) is almost consistent with the variation of irrigation use. The water level of this borehole is considered to represent the change of irrigation use (Fig. 12-19).

The unit consumption for irrigation was calculated based on the groundwater use of the permit holders and irrigated areas of the Hydrocensus. Using the allocated amounts, the unit consumption becomes 42.0 m^3/day/ha. Using the reported products, the unit consumptions are 28.6 m^3/day/ha in 1998 and 26.0 m^3/day/ha in 1999 respectively. Excluding farms with very small consumption values, the unit consumptions become 34.0 m^3/day/ha in 1998 and 31.0 m^3/day/ha in 1999 (Table 12-14).

5) Present Groundwater Use by Usage Type

Basically using the unit consumptions of the Hydrocensus (Table 12-16), present groundwater use was estimated. Results are shown in Table 12-17 and Fig. 12-20. Total groundwater use in the study area is estimated to be 40,912 m^3/day (14.9 million m^3/year). Irrigation use amounts to 18,868 m^3/day (6.9 million m^3/year) and is 46% of total use. Stock watering use is 15,589 m^3/day (5.7 million m^3/year) and 38%. Domestic use is 6,455 m^3/day (2.4 million m^3/year) and 16%.

The distributions of present groundwater use by usage in each cell are shown in Figs. 12-21 to 12-24. The estimated groundwater use in a farm was divided among boreholes belonging to that farm. Then, the groundwater uses of boreholes were summed up for each cell. The location of boreholes was based on the results of the Hydrocensus and the DWA Database.

Domestic use is generally distributed over the study area. Pumping rate of almost cells is less than 10 m^3/day. Near Aranos, there is only one cell with large pumping rate that is more than 500 m^3/day (Fig. 12-22). Stock watering use is also generally distributed over the study area except the Aminuis region. Pumping rate of almost cells is less than 30 m^3/day. There is no cell whose pumping rate is more than 500 m^3/day (Fig. 12-23). Irrigation use centres on the Stampriet region, and expands along the Auob River and the road from Stampriet to Aranos. There is one cell whose pumping rate is more than 2000 m^3/day. The ratio of cell with large pumping rate is high comparing with domestic or stock watering use (Fig. 12-24). Total groundwater use coincides with irrigation use in heavy pumping area. Generally groundwater use is dense in western half of the study area (Fig. 12-21).

6) Present Groundwater Use by Aquifer

(1) Present Groundwater Use by Aquifer

The estimated groundwater use in each borehole was divided into the aquifers based on the borehole construction information (i.e. screen depth, borehole depth, water strike depth) and the isodepth maps of aquifers. Unfortunately there are few boreholes with complete information. Therefore, dividing of the groundwater use into aquifers was done through the procedure shown in Table 12-18.

Results are shown in Table 12-19 and Figs. 12-25 to 12-31. Groundwater use from the Kalahari Aquifer amounts to 26,739 m^3/day (9,8 million m^3/year) and occupies 65% of total use. Groundwater use from the Auob Aquifer is estimated to be 13,622 m^3/day (5.0 million m^3/year) and 33%, and that from the Nossob Aquifer is merely 551 m^3/day (0.2 million m^3/year) and 1% (Fig. 12-25).

The domestic use from the Kalahari Aquifer amounts to 69% of total domestic use. These from the Auob Aquifer and the Nossob Aquifer are 24% and 7% respectively

(Fig. 12-26). For the stock watering use, groundwater from the Kalahari Aquifer occupies 81%, and that from the Auob Aquifer is 19% (Fig. 12-27). The irrigation use is equally shared between the Kalahari Aquifer and the Auob Aquifer (Fig. 12-28).

In the Kalahari Aquifer, the stock watering use is 47%, and the irrigation and domestic use are 36% and 17% respectively (Fig. 12-29). In the Auob Aquifer, the irrigation use is prominent and is 67%. The stock watering and domestic use are 22% and 11% respectively (Fig. 12-30). In the Nossob Aquifer, the domestic use is 88%, and the irrigation and stock watering use are only 10% and 2% respectively (Fig. 12-31).

(2) Distribution of Present Groundwater Use by Aquifer

The distributions of present groundwater use by aquifer in each cell are shown in Figs. 12-32 to 12-34. The distributions of each usage by aquifer are shown in Figs. 12-35 to 12-43.

Groundwater use of the Kalahari Aquifer is distributed over almost all study area. Heavy pumping cells are concentrated in the Stampriet region, and there is a cell with pumping rate of 1,000-2,000 m^3/day. Along the Auob River, cells with relatively large pumping rate expand (Fig. 12-32). Groundwater use of the Auob Aquifer is centred at the Stampriet region, and there is a cell whose pumping rate is more than 2,000 m^3/day. Cells with small pumping rate spreads in the area to the southeast of Aranos (Fig. 12-33). Groundwater use of the Nossob Aquifer is dotted around the study area (Fig. 12-34).

The domestic use of the Kalahari Aquifer extends over the study area. The pumping rate of cells is generally less than 10 m^3/day (Fig. 12-35). The distributed area of the domestic use of the Auob Aquifer is smaller than that of the Kalahari Aquifer. The pumping rate is almost less than 10 m^3/day (Fig. 12-36). The domestic use of the Nossob Aquifer is very similar to total groundwater use of it (Fig. 12-37).

The stock watering use of the Kalahari Aquifer is widely distributed except Aminuis area. Pumping rate is generally less than 30 m^3/day. In the south-western part of the study area, there are several cells with pumping rate of 100-500 m^3/day (Fig. 12-38). In the Auob Aquifer, the stock watering use is distributed around Stampriet, Aranos and Leonardville. Pumping rate is almost less than 30 m^3/day (Fig. 12-39). The stock watering use of the Nossob Aquifer is scarce (Fig. 12-40).

The irrigation use of the Kalahari Aquifer is concentrated to the Stampriet region, and expands along the Auob River and the road from Stampriet to Aranos (Fig. 12-41). That of the Auob Aquifer is only centred on Stampriet region. There is a cell whose pumping rate is lager than 2000 m^3/day (Fig. 12-42).

7) Variation of Groundwater Use

The groundwater use variation from 1990 to 1999 was estimated by using the statistics and existing data (Table 12-20). In the domestic use, groundwater use variation in commercial farms and communal land was calculated from the population change. For commercial farms, annual population growth was estimated to be 0.68% based on the 1991 Population and Housing Census and the Hydrocensus. For communal land, annual population growth was estimated to be 2.14% in Aminuis and 2.48% in Nama land (see Chap.10). For village centre, the productions of NamWater (Table 12-13) were used directly.

The variation of the stock watering use was estimated by number of livestock. Based on the Hydrocensus 1986-1989 (DWA, 1986; 1987; 1989), the stock watering use in Area 1-3 amounted to 883,600m3/a, using unit consumptions 35 Litter/head for LS and 5 Litter/head for SS (Table 12-21). Based on the Hydrocensus, the stock watering use in the same area was estimated to be 735,000 m3/a, using the same unit consumptions. From these figures annual growth was calculated to be –1.82%.

From 1994 to 1999, production of the permit holders (Table 12-14) was used directly estimating the irrigation use variation. From 1990 to 1993, exponential approximation equation of productions from 1994 to 1999 was used (y=2.9754exp(0.1017x); y: annual production, x=year-1993).

The estimated results are shown in Table 12-22 and Figs 12-44 and 12-45. The groundwater use increased from 11.6 million m^3/year in 1990 to 14.9 million m^3/year in 1999. The stock water use decreased from 6.7 million m^3/year and 58% of total in 1990 to 5.7 million m^3/year and 38% in 1999. On the other hand, the irrigation use increased 2.7 million m^3/year and 23% of total in 1990 to 6.9 million m^3/year and 46% in 1999 (Fig. 12-44).

Groundwater from the Kalahari Aquifer increased from 8.4 million m^3/year in 1990 to 9.8 million m^3/year in 1999. That from the Auob Aquifer rapidly increased from 3.0 million m^3/year to 5.0 million m^3/year (Fig. 12-45).

12.5.7 Recharge

It is difficult to estimate the groundwater recharge based on the runoff analysis (see section 2.2). Therefore, the groundwater balance analysis was applied to estimate it.

1) Groundwater Balance in An Area

The groundwater balance in an area is expressed as follows.

$$R - D = S\frac{dh}{dt} \quad (12-14)$$

Where, *R*: recharge rate, *D*: discharge rate, *S*: storativity, *dh/dt*: groundwater level change in unit time. *R* means the groundwater inflow, *D* means the groundwater outflow and *Sdh/dt* is the storage change of groundwater in the area.

For the period without recharge, a regression curve of groundwater level is expressed by following exponential-type equation.

$$\frac{dh}{dt} = C(h - h_0) \quad (12-15)$$

Where, *h*: groundwater level, h_0: standard groundwater level (at this level, discharge rate becomes zero), *C*: constant. Substituting equation (12-15) into equation (12-14), the discharge rate (*D*) can be expressed as follows (where, R=0).

$$D = -SC(h - h_0) \quad (12-16)$$

For the recharge period, a recharge rate (*R*) is expressed following equation, substituting equation (12-16) into equation (12-14).

$$\begin{aligned} R &= -SC(h - h_0) + S\frac{dh}{dt} \\ &= S\left\{\frac{dh}{dt} - C(h - h_0)\right\} \quad (12-17) \end{aligned}$$

From equation (12-17) the recharge rate can be estimated reading groundwater level on the observation borehole records.

2) Recharge Estimation at Olifantswater

To estimate the recharge rate by the above method, it needs to select an observation borehole that represents natural recharge. Of course the recharge rate cannot be estimated from an observation borehole influenced heavily by pumping.

The Olifantswater WW21815 was selected for the recharge estimation. It has observed the groundwater level in the unconfined Kalahari aquifer. The groundwater level change of WW21815 differs from that of the Spes Bona WW32457, which is strongly effected by the irrigation groundwater use (see Fig. 12-19). It is considered to represent the natural recharge-discharge process.

The water level of WW21815 shows a tendency to decrease annually. To calculate C and h_0, it is necessary to make a correction of the water level. As shown in Fig. 12-46, the correction value is 0.61m for 11 years (i.e. 5.5cm/year). The calculated C and h_0 are 0.0167 and -15.245m respectively (Fig. 12-47).

Using equations (12-16) and (12-17), the monthly discharge and recharge rates were calculated. For the recharge calculation, it was assumed that the recharge occurs when water level is rising, and it equals zero when water level is declining. The results are shown in Fig. 12-46. Annual values are summarized in Table 12-24.

The discharge and recharge rates calculated from equations (12-16) and (12-17) are proportional to the storativity that equals the effective porosity in unconfined aquifer. The results of neutron logging of the JICA test boreholes show that the porosity of the Kalahari aquifer is about 25%. Using this value as an effective porosity, the calculated recharge rate exceeds rainfall. Therefore, the effective porosity is smaller than the porosity estimated by the neutron logging, and it seems that value from 2% to 5% is adequate.

These values were used for the initial setting of model calibration, and were revised in process of the calibration.

12.6 Model Calibration

12.6.1 Procedure of Model Calibration

Model calibration was carried out in the following steps:

a. Calibrating groundwater level distribution by the steady-state calculation

b. Calibrating groundwater level variation by the unsteady-state calculation

c. Calibrating groundwater level change caused by 1/50 years rain (in 2000)

The first step of model calibration is to clarify the hydraulic conductivity and to make initial heads (1990) for unsteady-state calculation. Calculated heads were compared with groundwater level distribution based on the groundwater level survey. The second step of yearly unsteady-state calculation from 1990 to 1999 is to clarify the specific storage and recharge rate. Calculated head variations were compared with water level records of DWA and NamWater. Third step is to clarify the recharge rate with 1/50years rain (in 2000). Calculated head was compared with observed water level, then parameters (mainly hydraulic conductivity) and recharge rate were modified until final agreement between the calculated and the observed water level is achieved.

12.6.2 Calibrated Model

1) Comparison between Observed and calculated results

(1) Groundwater Level Configurations

Calculated heads were compared with results of the groundwater level survey. The results of survey show distribution of groundwater level in 2000. Groundwater level changes between 1990 and 2000 are relatively small, therefore the configuration of groundwater level is considered to be almost unchanged. Calculated heads were also verified by observation well records of Jan. 1990.

Fig. 12-48 shows observed and calculated groundwater level configurations of the Kalahari Aquifer. From the 1300m to 1100m contours, calculated and observed heads are almost coincided. On the 1000m and 950m contours, differences between calculated and observed heads are slightly large. In that area, there were few measuring points therefore strict comparison is difficult. Comparison of the Auob Aquifer is shown in Fig. 12-49. From the 1300m to 1050m contours, calculated and observed heads well agree. The 1000m and 950m contours of the both are not in agreement. Fig. 12-50 shows the configuration of the Nossob Aquifer. From 1250m to 1100m contours, the both are well coincided. In the eastern and southern part of the model, the both do not entirely agree. In these areas, configuration of observed head is not accurate since there are few measuring points.

Fig.12-51 shows comparison of observed and calculated heads at observation wells. If the both values coincide, corresponding point is plotted on a line of 45 ° angle. All points distributes along the line of 45 ° angle. The mean error that is the mean difference between measured and calculated head is 1.0m. The results indicate good agreement of the two.

(2) Variations of Groundwater Level

Observed and calculated groundwater level variations in 1990-1999 at observation wells are shown in Figs. 12-52 to 12-59. Observations are monthly, but calculated results are yearly. At Olifantswater, calculated heads of the Kalahari Aquifer well agree with the trend of observed groundwater level (WW21815). Calculated heads of the Auob Aquifer are approximately 1 meter higher than the observed one (WW21784). However, these well simulates the declining trend of the observed records (Fig. 12-52). At Gomchanas (WW8399) calculated heads are about 1.5 meters lower than observed groundwater level. Decline of calculated heads is slightly smaller than that of the observation (Fig. 12-53).

At Spes Bona calculated heads are approximately 2 meters lower than the observed heads (WW32457), however these well agree with the trend of observed variations (Fig. 12-54). Calculated heads at Boomplaas correspond to the observation (WW10120). These in 1998 and 1999 are slightly lower than the observation (Fig. 12-55).

At Tugela (WW22838) calculated heads of the Kalahari Aquifer are about 3 meters lower than the observed heads and these of the Auob Aquifer are about 4 meters lower than the observed ones. Both of calculated heads well coincide with the trend of declining observation records. Calculated heads of the Nossob Aquifer is approximately 5 meters higher than the observation. Decline of calculated heads is slightly smaller than that of the observation (Fig. 12-56).

At Gochas calculated heads of the Kalahari and Auob Aquifers are almost unchanged. Levels of the both correspond to the observation (WW7491, WW16343) approximately (Fig. 12-57). Calculated head of the Nossob Aquifer at Aranos well agree with the observed heads (WW7407) (Fig. 12-58). At Aminuis calculated heads are about 1 meter lower than the observed groundwater level (WW26164). Since observed variation is irregular, it is difficult to compare the trends of both (Fig. 12-59)

Gochas(WW7491, WW16343), Aranos(WW7407) and Aminuis(WW26164) are NamWater scheme wells. Therefore groundwater change caused by pumping is large, and it is difficult to clarify the trend of variation.

(3) Groundwater Level Change with 1/50 years rain

Groundwater level recovery in 2000 caused by heavy rain in 1999-2000 was calibrated, assuming pumping rates in 2000 and 2001 to be the same as that in 1999. Results are also shown in Figs. 12-52 to 12-59.

Calculated heads of the Kalahari Aquifer agree well with the observed recovery at Olifantswater. In the Auob Aquifer groundwater level recovery has not observed, however calculated heads indicate a little recovery (Fig. 12-52). At Gomchanas the observed records shows slight recovery and calculated head agree with it (Fig. 12-53).

Though observed heads at Spes Bona shows about 3 meters recovery, calculated heads continue to decline. This recovery is considered to arise from pumping rate change. In the calculation pumping rate in 2000 is the same as that in 1999, therefore the calculated heads do not agree with the observed recovery (Fig. 12-54). At Boomplaas, calculated and observed heads indicate the same situation as Spes Bona (Fig. 12-55).

At Tugela calculated heads of the Kalahari and Auob Aquifers coincide with about 2 meters recovery of the observed heads. Calculated heads of the Nossob Aquifer do not agree with slight recovery of observation (Fig. 12-56).

At Gochas, Aranos and Aminuis groundwater level recovery in the observed records are not distinct for the above-mentioned reason (Figs. 12-57 to 12-59).

2) Water Budget in Calibration Period

Water Budget in 1999 and 2000 is given in Figs. 12-60 and 12-61. In 1999, well pumping rate (38,400 m^3/day) considerably exceeded recharge rate (12,600 m^3/day). To compensate this shortage, water released from the storage (24,000 m^3/day) declining groundwater level. Pumping rate of the model doesn't agree with that of the study area, since the model area is smaller than the study area (Fig. 12-60).

In 2000, recharge rate (218,800 m^3/day) increased by about 17 times that of 1999. With 1/50years rain, groundwater level recovered and the storage increased (181,900 m^3/day) (Fig. 12-61).

3) Fixed Parameters

Hydraulic conductivity, Specific Storage (effective porosity) and recharge rate were modified to calibrate the model. The distributions of fixed hydraulic conductivity of model layer 1 to 6 are shown in Figs.12-62 to 12-67. The distribution of fixed specific storage and effective porosity of model layer 4 and 6 are shown in Figs. 12-68 and 1-69. Fixed hydraulic conductivity, specific storage and effective porosity are summarized in Table 12-25. Zone number in Figs. 12-62 to 12-69 corresponds to that in Table 12-25. Specific storage and effective porosity of model layer 1 to 3, and 5 sets uniformly to be zone 1.

Recharge rate is summarized in Table 12-26 and distribution of zones is shown in Fig. 12-70. Zone number in Fig. 12-70 corresponds to that in Table 12-26. In ordinary years (1990-1999), recharge rate is very small except zone 6. Results of Carbon-14 and Tritium analysis support this low recharge rate. At zone 6 relatively large recharge rate was needed to prevent cells form drying up, since the aquifers locate at high altitude. In 2000 with 1/50years rain, recharge rate increased to about 1 to 3% of annual rainfall to calibrate the groundwater level change at observation wells.

12.7 Model Prediction

12.7.1 Prediction Cases

1) Pumpage

To predict the groundwater level change caused by pumping rate change, 6 cases shown in Table 2-27 were studied. Cases 1 and 2 were assumed to keep present groundwater use. For case 3 irrigation use was increased to 120% of present. For cases 4 to 6 irrigation use was decreased to 70%, 50%, 0% respectively. Indicating the calibration results, groundwater level depletion in Stampriet area is major problem in the basin. Therefore change of irrigation use that causes the depletion was studied. Prediction period for each case is 100 years.

2) Recharge

Recharge rate will vary in prediction period, but there is no precise recharge analysis to obtain probability of recharge at present. Calibrated recharge rate was used as an average of long period. For Cases 2 to 6, recharge rate with1/50years rain was assumed in 30th and 80th year (Fig. 12-71).

12.7.2 Constraints on Permissible Yield

As mentioned in section 12.1.1, constraints on permissible yield are social scientific matter except water balance. Therefore it is difficult to define the constraints. Here, following constraints are assumed. These are not complete and should be revised with exhaustive argue.

1) Water Balance Constraint

Groundwater abstraction should be within the possible amount of recharge on arbitrary spatial and time scales. In this study time scale is determined to be one year, therefore annual amount of pumpage must not exceed that of the possible recharge. In other words, the groundwater level must recover to the initial level at the end of one hydrologic year. Following table shows the criteria for the annual residual drawdown.

Criteria for Water Balance Constraint

Rank	Annual Residual Drawdown (m)	Description
A	0.00 – 0.03	Allowable: Not surely safe, but allowable if there is no alternative plan
B	0.03 – 0.10	Undesirable: The aquifer storage will be possibly depleted in future
C	0.11 -	Not Allowable: The aquifer storage will be probably depleted in near future

2) Water Quality Constraint

In this simulation groundwater quality is not studied, since groundwater level change is considered to be small and it would not cause groundwater quality change. However, there are high salinity zones (“salt blocks”), and groundwater quality is one of the problems in this basin. Prediction of groundwater quality is the subject for a future study.

3) Environmental Constraint

Influences on existing springs and vegetations are possible environmental constraints to be considered. According to the environmental analysis (see Chap. 14), springs in this basin already dried up decades ago. Therefore, the impact on existing springs can be negligible. Decline or recovery of groundwater level will affects the vegetations in this basin. However, no quantitative analysis on the relationship between groundwater level and vegetations has been done. In this study, the influence on vegetations was neglected.

It is the subject for a future study.

4) Economical Constraint

This constraint comes from the limits of pump lift. Average PID (Pump Installed Depth) is 46 meters and average groundwater level depth is 29 meters based on the Hydrocensus. As a result, the total drawdown should be within about 10 meters. Otherwise the pump must be altered to suit deeper water level, which will cost more. Criteria for the economic constraint are shown in the following table.

Criteria for Economic Constraint

Rank	Total Drawdown after 100 years (m)	Description
A	0 – 10	Good: No problems in practical use
B	10 – 20	Allowable: Well yield may decrease
C	20 >	Undesirable: Pump should be changed

12.7.3 Model Prediction

In Figs. 12-72 to 12-89, predicted results are shown as drawdown after 100 years for each aquifer and case. Calculation of bottom area of the model was unstable and there were incomprehensible head differences. These differences were ignored in figures. Also, groundwater level variations at observation wells are shown in Figs. 12-90 to 12-92.

1) Case 1

Groundwater pumpage is kept at the rate of 1999 (14.9 million m^3/ year) in this case. Maximum drawdown of the Kalahari Aquifer will exceed 30 meters, and the Kalahari Aquifer will dry up within 35 years at Spes Bona (Figs. 12-72 and 12-91). It corresponds to the rank C (Not Allowable) of water balance constraint and the rank C (Undesirable) of economic constraint. In Stampriet area there is no observation well of the Kalahari Aquifer then the predicted results are not calibrated. However, the results can show the trend of the variation of groundwater level. Maximum drawdown in the Auob Aquifer is 14 meters at Stampriet (Figs. 12-78 and 12-91). It corresponds to the rank C (Not Allowable) of water balance constraint and the rank B (Allowable) of economic constraint. When a cell dries up, the MODFLOW automatically eliminates pumpage in that cell. Therefore, the groundwater level in the Auob Aquifer is slightly recovered, when the Kalahari Aquifer dries up and the pumpage of the aquifer is eliminated.

At Olifantswater drawdown in the Kalahari Aquifers is 3 meters and that of the Auob

Aquifer is 3 meters also (Fig. 12-90). These correspond to the rank A (Allowable) of water balance constraint and the rank A (Good) of economic constraint. At Tugela drawdown in the Kalahari Aquifer is 1 meter. It corresponds to the rank A of water balance and economic constraints. Drawdown in the Auob and Nossob Aquifers are 5 meters and 4 meters respectively (Fig. 12-92). These classified into the rank B (Undesirable) of water balance constraint and the rank A of economic constraint.

2) Case 2

Pumping rate is the same as that of Case 1 (14.9 million m^3/ year). In 30th and 80th years it is assumed to get recharge with 1/50years rain. At Spes Bona drawdown in the Kalahari and Auob Aquifers are the same as these of Case 1 (Figs. 12-73 and 12-79). The Kalahari Aquifer will dry up within 35 years (Fig. 12-91). The classifications are the same as these of Case 1. In the Stampriet area no recharge condition is set (Fig. 12-70), therefore no groundwater level recovery is calculated in the year with 1/50years rain. The drawdown of the Kalahari Aquifer is accelerated with increase of groundwater level decline. The Kalahari Aquifer is unconfined aquifer. When a decline of groundwater level becomes larger, the transmissivity of unconfined aquifer becomes smaller. Pumping rate in the aquifer is constant. Therefore, acceleration of decline is observed.

At Olifantswater groundwater level of the Kalahari Aquifer shows the recovery of about 0.4 meters in the year with 1/50years rain. Drawdown for 100 years reaches about 2.6 meters. Groundwater level of the Auob Aquifer shows the recovery of about 0.2 meters in the year with 1/50years rain. Total drawdown is about 2.2 meters (Fig. 12-90). These correspond to the rank A of water balance and economic constraints.

At Tugela groundwater level of the Kalahari Aquifer indicates the recovery of 0.7 meters in the year with 1/50years rain. The recovery of the Auob Aquifer with that rain is 0.6 meters. Total drawdown of the Kalahari Aquifer is 0.8 meters. These of the Auob and Nossob Aquifers are 3.0 meters and 2.8 meters respectively (Fig. 12-92). The results are classified into the rank A of water balance and economic constraints.

3) Case 3

Pumping rate of irrigation use is increased to 120% in this case. Total pumping rate is 109% of Case 1 (16.3 million m^3/ year). Maximum drawdown of the Kalahari Aquifer will exceed 30 meters, and the Kalahari Aquifer will dry up within 25 years at Spes Bona (Figs. 12-74 and 12-91). It corresponds to the rank C of water balance constraint and economic constraint. Maximum drawdown in the Auob Aquifer exceeds 20 meters at Stampriet (Figs. 12-78 and 12-91). It corresponds to the rank C of water balance and economic constraints.

At Olifantswater groundwater levels of the Kalahari and Auob Aquifers are slightly lower than these of Case 2. The differences of total drawdown between the both are less than 0.1 meters (Fig. 12-90). These correspond to the rank A of water balance and economic constraints. At Tugela groundwater level of the Kalahari Aquifer is almost the same as that of Case 2. Drawdown of the Auob and Nossob Aquifers are 0.05 and 0.1 meters lower than these of Case 2 (Fig. 12-92). These are classified into the rank A of both constraints.

4) Case 4

In this case the pumping rate of irrigation use is reduced to 70% of Case 1. Total pumping rate is 86% of Case 1 (12.9 million m^3/ year). At Spes Bona the period to dry up in the Kalahari Aquifer extends for 80 years (Fig. 12-91). However, maximum drawdown in Stampriet area exceeds 30 meters (Fig. 12-75). It corresponds to the rank C of water balance and economic constraints. Total drawdown of the Auob Aquifer at Spes Bona is 3.4 meters. Maximum drawdown in Stampriet area is less than 10 meters (Fig. 12-81). It is classified into the rank B of water balance and the rank A of economic constraint.

At Olifantswater groundwater level of the Kalahari and Auob Aquifers are 0.06 to 0.15 meters higher than these of Case 2, and are classified into the rank A of water balance and economic constraints (Fig. 12-90). At Tugela groundwater level of the Kalahari Aquifer is almost the same as that of Case 2. Drawdown of the Auob and Nossob Aquifers are 0.07 and 0.21 meters higher than these of Case 2 (Fig. 12-92). These are classified into the rank A of both constraints.

5) Case 5

The pumping rate of irrigation use is reduced to 50% of Case 1 in this case. Total pumping rate is 77% of Case 1 (11.5 million m^3/ year). At Spes Bona total drawdown of the Kalahari Aquifer is almost 0 meter, however total drawdown of 5 to 9 meters remains in Stampriet area (Figs. 12-76 and 12-91). The water balance constraint is the rank B and economic constraint is the rank A. Total drawdown of the Auob Aquifer is 3.0 meters, and it corresponds to the rank A of both constraints (Figs. 12-82 and 12-91).

At Olifantswater groundwater level of the Kalahari and Auob Aquifers are 0.1 and 0.25 meters higher than these of Case 2, and correspond to the rank A of both constraints (Fig. 12-90). At Tugela groundwater level of the Kalahari Aquifer is almost the same as that of Case 2. Drawdown of the Auob and Nossob Aquifers are 0.12 and 0.25 meters higher than these of Case 2 (Fig. 12-92). These are classified into the rank A of both constraints.

6) Case 6

The pumping rate of irrigation use is reduced to 0% (abolishing irrigation) of Case 1 in this case. Total pumping rate is 54% of Case 1 (8.1 million m^3/ year). At Spes Bona groundwater level of the Kalahari Aquifer shows the recovery of 21 meters (Fig. 12-77 and 12-91). It corresponds to the rank A of water balance and economic constraints. Groundwater level of the Auob Aquifer shows the recovery of 15.5 meters, and it corresponds to the rank A of both constraints (Figs. 12-83 and 12-91).

The model layer 1 and 2 correspond to the Kalahari Aquifer as mentioned before. The model layer 1 at Spes Bona is dry cell (inactive) in the calibration periods and the bottom altitude of it is 1155m. The model layer 2 is unconfined until groundwater level recovers to 1155m. When groundwater level reaches to 1155m, the model layer 2 becomes confined condition. Storativity of confined aquifer is smaller than that of unconfined aquifer in two orders. Then groundwater level recovers suddenly in 2014. This recovery causes the model layer 1 to be active (re-wetting). The model layer 1 is unconfined and the groundwater level recovery becomes to be gradual.

At Olifantswater groundwater level of the Kalahari and Auob Aquifers are 0.25 and 0.5 meters higher than these of Case 2, and correspond to the rank A of both constraints (Fig. 12-90). At Tugela groundwater level of the Kalahari Aquifer is almost the same as that of Case 2. Drawdown of the Auob and Nossob Aquifers are 0.25 and 0.7 meters higher than these of Case 2 (Fig. 12-92). These are classified into the rank A of both constraints.

12.8 Evaluation of Permissible Yield

12.8.1 Permissible Yield in the Basin

1) Water Balance

Results of water balance in prediction period are shown in Figs. 12-93 to 12-103 for ordinary year (after 10 years) and year with 1/50years rain (after 30 years). After 30 years pumping rate from wells reduced since pumping rate of dry cells is eliminated by the MODFLOW. In ordinary year total groundwater outflow (pumping + outflow at boundary) exceeds the groundwater inflow (recharge + inflow from boundary) and is compensated by the groundwater storage release, declining groundwater levels. In year with 1/50years rain, the groundwater inflow exceeds temporarily the groundwater outflow and increases the groundwater storage, recovering groundwater levels.

2) Results of Prediction

As shown in previous section, predicted results in Stampriet area are different from these of other area. Therefore, the results were evaluated for Stampriet area and remaining other area respectively. Results of the model prediction in the Stampriet Basin were summarized as bellow:

Relation to Expected Constraints

Area	Stampriet area				Other area			
Constraint	Water Balance		Economic		Water Balance		Economic	
Aquifer Case	Kala	Auob	Kala	Auob	Kala	Auob	Kala	Auob
1	NA	NA	UD	A	A	A/UD	G	G
2	NA	NA	UD	A	A	A	G	G
3	NA	NA	UD	UD	A	A	G	G
4	NA	UD	UD	G	A	A	G	G
5	UD	A	G	G	A	A	G	G
6	A	A	G	G	A	A	G	G

Remarks: G=Good, A=Allowable, UD=Undesirable, NA=Not Allowable
Kala = Kalahari Aquifer, Auob = Auob Aquifer

3) Permissible Yield

Present groundwater abstraction (Case1, Case 2) is acceptable in the Stampriet Basin except Stampriet area. In this area groundwater is mainly used for stock watering and domestic purposes. It is considered that groundwater use will not increase remarkably. In Tugela area declines of groundwater level are slightly large with present groundwater pumpage. Careful monitoring is necessary.

In Stampriet area, the Kalahari Aquifer will dry up in near future, if present groundwater abstraction is kept. From the above results, pumping plan of Case 5 (reducing irrigation use to 50%) and Case 6 (reducing irrigation use to 0%) are acceptable in Stampriet area. Case 4 (reducing irrigation use to 70%) is not allowable since the Kalahari Aquifer will dry up within 80 years. To prevent the dry-up of aquifer, groundwater pumping for irrigation use is at least reduced to 50% of that in 1999, which is almost the same as the irrigation use in 1992.

4) Steps to Permissible Yield

(1) Schedule of Protective Measures

As protective measures differ for each area, their specific schedule needs to be suitably set respectively for each area. Based on the experience in Japan, the following stages can be considered in general (Shibasaki et al., 1995).

i) Research Stage

A preliminary reconnaissance based on available information is carried out in order to learn the general conditions of the basin. For all the boreholes in the basin, registration, arrangement of well inventory, measurement of groundwater level and pumping rate, and submission of its report should be ensured.

Base on these data, a preliminary review is carried out, minimum level of facilities for monitoring is set up, and the permissible (yield) critical groundwater level is tentatively worked out. In this stage, construction of new boreholes is strictly regulated.

The period for the first stage is desirably within a few years, even for areas without substantial data.

ii) Observation and Arrangement Stage

Based on the permissible critical groundwater level determined initially in the first stage for each area, groundwater level and extraction are observed, and groundwater pumpage for each area is reduced. The deduction of groundwater pumpage is closely related to the socio-economic factors as well as with the general utilization of water resources including the possibility of development of alternative water sources such as dams.

In the second stage, the monitoring system is further improved, and the data are comprehensively analyzed. Then for each area, each municipal unit (cities and towns), of for smaller zones, permissible yield are determined. For this second stage, a period of five years would be practical.

iii) Stage for Intensive Enforcement Measures

As long as measures are strictly enforced in the second stage, the objectives to stop groundwater problems may be considered to be mostly achieved. If groundwater level still cannot be regained, a third stage may be considered in which intensified restriction on pumpage, intensive alteration of water sources, and measures for artificial recharge should be resorted to.

For the realization of effective groundwater basin management, besides technological improvements, legal and social issues such as the improvement of groundwater utilization system should be considered.

(2) Steps to Permissible Yield in the Study Area

For the study area, groundwater management may be in a transition period from the first stage to the second stage. For the present, observation of groundwater levels should be continued using the monitoring system that made by this study. Improving the groundwater model based on the observation results, tentative permissible yield in this study should be revised precisely.

Urgent measures to be taken are preventing the increase of groundwater abstraction. In order to achieve this, it is important to inform farmers of the present situation in the basin, and to make farmers understand the problems that will occur with present groundwater use. Therefore the farmers may be cooperative to reduce the pumpage.

Meanwhile measures reducing pumping rate to the permissible yield should be prepared. It is considered to apply permits strictly to irrigation use. Charging system for groundwater use is worth considering.

12.8.2 Future Improvement in Modelling

The modelling of the Stampriet Artesian Basin is based on the knowledge at present. Therefore, modification of the model will be expected in future observations and investigations.

There is no observation well of the Kalahari Aquifer in Stampriet area, where serious problems are estimated to occur in near future. New Kalahari observation wells are necessary to monitor the variation of groundwater level and to improve the model accuracy.

The calculation model in this study was unstable at the bottom area of the model and there were incomprehensible head differences. Future improvement is necessary to enhance the model accuracy.

Groundwater pumping rate was estimated by using many assumptions. The reports from permit holders are incomplete. It is necessary to report monthly abstraction properly. For domestic and stock watering use, there are no data on the variation of pumping rate. It is recommended to select sample wells and to install the flow meter.

The recharge rate is unknown at present. A basic hydrologic and hydrochemical study is necessary to estimate accurate recharge rate.

The model calibration should be improved based on the future studies above mentioned and the observation results of the monitoring system. It is recommended to model the groundwater quality, investigating the influence of “salt block”.

Table 12-1 Hydrogeological Structure in the Stampriet Artesian Basin

Formation			Lithology	Hydrogeological Structure	
				Aquifer Type	Conceptual Model
Kalahari Beds			Sand, Gravel, Calcrete	Unconfined aquif	Unconfined aquifer (aquitard) (aquitard) Leakage
Karoo Sequence		Karoo Dolerite	Dolerite	Aquitard-	
		Kalkrand Basalt	Basalt	Unconfined aquif	
	Ecca Group	Rietmond membe	Sandstone	Unconfined- confined aquifer	
			Shale	Aquitard	1st confining layer absent
		Auob member	Sandstone	Confined aquifer	1st confined aquifer
			Shale	Aquitard	
		Mukorob member	Sandstone	Confined aquifer	
			Shale	Aquitard	2nd confining layer
		Nossob member	Sandstone	Confined aquifer	2nd confined aquifer
	Dwyka Group		Tillite, Mudstone	Basement	Hydrogeological Basement
Nama Group			Sandstone, Shale	Basement	
Damara Sequence			Metamorphic rock	Basement	

Table 12-2 Combination of Aquifers and Aquitards

	B	C	K	M	A	L	P	Q	R	S	T	V	W	X	Y	D	E	I	J	G	H	0
Kalahari Beds	–	X	X	X	X	X	X	X	X	X	X	X	X	X	X	–	–	–	–	–	–	–
Basalt	X	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Upper Rietmond	–	–	–	–	–	–	X	X	X	–	–	X	X	X	X	X	X	X	X	–	–	–
Lower Rietmond	–	–	–	–	–	X	X	X	X	X	X	X	–	–	–	–	–	X	X	X	–	–
Auob Aquifer	–	–	–	–	X	–	X	–	X	X	–	X	X	–	X	X	–	X	–	X	–	–
Lower Mokorob	–	–	–	X	X	–	X	X	–	X	X	–	X	X	–	X	X	X	X	X	X	–

1) Basalt: Kalkrand Basalt

2) The Nossob Aquifer is assumed to be isolated form upper aqufers

Table 12-3 Combination of Aquifers and Aquitard for Each Cell

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	K	K	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	W	W	R	L	L	0	0	0	0	0	0	0	0	0	K	K	K	K	K	K
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Y	Y	W	R	L	K	K	0	0	0	0	K	K	K	K	K	K	K	K	K	K
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	W	P	P	R	R	R	R	L	L	L	X	X	X	X	P	P	S	S	S	S	S
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	L	P	P	P	P	R	R	R	P	P	P	P	W	W	W	W	P	S	P	P	P	P	P
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	R	P	P	P	P	P	P	P	P	P	P	P	P	W	W	W	P	P	P	P	P	P	P
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	L	R	R	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	Y	R	R	V	R	P	S	P	P	P	P	P	P	P	P	P	P	P	S	S	A	A	A	A	A
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Y	R	R	R	R	R	P	S	P	P	P	P	P	P	P	P	P	S	A	A	A	A	A	A	A	A
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	R	R	R	R	R	R	R	P	P	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	R	R	R	R	R	R	P	P	P	P	P	P	P	P	P	P	S	W	W	A	S	S	P	P	P	P	P
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K	R	R	R	R	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	S	S	S	S	S	S	S	S
16	0	0	0	0	0	0	0	0	0	C	C	C	C	C	C	C	Y	Y	0	0	Y	R	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
17	0	0	0	0	0	0	0	0	B	C	C	C	C	C	C	C	W	W	0	S	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
18	0	0	0	0	0	0	B	B	B	C	C	C	C	C	C	C	P	P	P	P	P	S	S	S	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
19	0	0	0	0	0	0	B	B	B	C	C	C	C	C	C	Y	P	P	P	P	P	S	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	W	W	W	W
20	0	0	0	0	B	B	B	B	B	C	C	C	C	C	C	W	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	P	P	P	P	W	W	W	W	W
21	0	0	B	B	B	B	B	B	B	B	C	C	C	C	C	W	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	W	W	W	P	P	P	P	P
22	0	0	B	B	B	B	B	B	B	B	B	B	C	C	C	W	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	W	W	W	P	P	P	P	P
23	0	0	0	B	B	B	B	B	B	B	B	B	B	C	W	W	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	W	W	W	W	W	P	W	W	W	W	W
24	0	0	0	0	B	B	B	B	B	B	B	B	B	B	W	W	P	P	P	P	P	P	P	P	P	P	P	P	P	P	W	P	P	P	W	W	W	W	W	W	A	W	W	W	W	W	W	W
25	0	0	0	0	0	B	B	B	B	B	B	B	B	B	B	P	P	P	P	P	S	P	P	P	W	W	A	A	A	A	A	P	P	P	P	P	W	W	W	A	A	W	W	W	W	W	W	W
26	0	0	0	0	0	B	B	B	B	B	C	C	C	B	B	P	P	P	P	P	S	S	S	P	W	A	A	A	A	A	A	A	A	A	P	W	W	A	A	A	W	W	P	W	W	W	W	W
27	0	0	0	0	0	0	B	B	B	B	C	C	C	C	B	P	P	P	P	P	P	S	P	S	A	A	A	A	A	A	A	A	A	A	A	W	A	A	A	W	W	W	W	W	W	W	W	W
28	0	0	0	0	0	0	0	B	B	B	B	C	C	C	B	B	P	P	P	P	S	S	S	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W	W	W	W	W	W	W	W	W
29	0	0	0	0	0	0	0	0	B	B	B	B	B	C	C	B	P	P	P	S	S	S	S	A	A	A	A	A	A	A	A	P	A	A	A	A	A	A	A	W	W	W	W	W	W	W	W	W
30	0	0	0	0	0	0	0	0	0	B	B	B	B	C	C	C	P	P	P	S	S	S	P	S	A	A	A	A	A	A	A	A	A	A	A	A	A	W	W	W	W	W	W	W	W	W	W	W
31	0	0	0	0	0	0	0	0	0	0	0	0	B	C	C	W	P	S	S	P	P	S	S	S	P	A	A	A	A	A	A	A	A	A	A	A	W	W	W	W	W	W	W	W	W	W	W	W
32	0	0	0	0	0	0	0	0	0	0	0	0	C	C	W	W	P	S	S	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	A	A	W	W	W	P	W	W	W	W	W	W	W
33	0	0	0	0	0	0	0	0	0	0	0	0	C	C	W	P	P	P	S	P	P	P	P	P	P	A	A	A	A	A	A	A	S	S	A	A	A	W	P	W	P	P	P	W	W	W	W	W
34	0	0	0	0	0	0	0	0	0	0	0	0	H	H	P	P	P	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	A	A	W	P	W	W	P	P	W	W	W	W	W
35	0	0	0	0	0	0	0	0	0	0	0	0	M	W	S	P	P	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	A	W	W	W	W	W	W	W	W	W	W	W	W
36	0	0	0	0	0	0	0	0	0	0	0	K	M	A	A	P	P	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	W	P	W	W	W	W	W	W	W	W	W	W	W
37	0	0	0	0	0	0	0	0	0	0	0	K	M	A	W	W	P	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	S	W	W	W	W	W	W	W	W	W	W	W	W	W	W
38	0	0	0	0	0	0	0	0	0	0	0	M	M	A	W	W	P	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	A	P	W	W	W	W	W	W	W	W	W	W	W	W
39	0	0	0	0	0	0	0	0	0	0	0	M	M	A	W	W	P	P	P	P	P	P	P	A	A	A	A	A	A	A	A	A	A	W	P	W	W	W	W	W	W	W	W	W	W	W	W	W
40	0	0	0	0	0	0	0	0	0	0	0	M	M	M	W	W	W	P	P	P	P	P	A	A	A	P	P	P	P	A	A	A	A	P	P	W	W	W	W	W	W	W	W	W	W	W	W	W
41	0	0	0	0	0	0	0	0	0	0	0	M	M	M	A	A	W	P	S	S	S	P	A	A	S	S	P	P	S	S	S	A	W	P	P	P	W	P	W	W	W	W	W	W	W	W	W	W
42	0	0	0	0	0	0	0	0	0	0	0	M	M	M	A	A	P	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
43	0	0	0	0	0	0	0	0	0	0	0	M	M	M	A	P	P	S	P	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	P	P	P	P	P	P	P	P	P	P	P	P	P
44	0	0	0	0	0	0	0	0	0	0	0	K	H	H	A	P	P	P	P	S	S	S	S	S	S	S	S	A	A	A	S	S	S	S	S	A	W	W	W	W	W	W	Q	P	P	P	P	P
45	0	0	0	0	0	0	0	0	0	0	0	0	0	H	H	P	P	S	P	S	S	S	S	S	S	S	S	A	A	A	A	A	A	A	A	A	W	W	W	W	W	Q	Q	P	P	P	P	P
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H	P	P	S	S	S	S	S	S	S	S	S	S	A	A	A	A	A	A	A	A	A	W	W	W	W	P	Q	Q	P	P	P	P	P
47	0	0	0	0	0	0	0	0	0	0	0	0	0	H	H	A	W	S	S	S	S	S	S	S	S	S	S	A	A	A	A	A	A	A	A	A	A	W	P	W	P	Q	Q	Q	Q	Q	Q	Q
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H	M	W	P	S	S	S	S	S	S	S	S	P	A	A	A	A	A	A	A	A	P	P	P	S	T	P	P	P	P	Q	Q	Q	Q
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H	M	P	I	G	I	P	S	S	S	P	P	P	A	A	A	A	A	A	A	A	S	S	S	S	T	S	P	S	P	Q	Q	Q	Q
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	D	I	I	G	G	I	P	P	S	S	P	P	A	A	A	A	A	A	A	A	A	S	S	S	T	T	T	S	P	Q	Q	Q	Q
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	E	I	I	G	G	I	S	S	S	P	P	P	P	A	A	A	A	A	A	A	A	A	A	A	T	T	Q	Q	L	L	L	L	L
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	J	I	I	I	I	S	S	S	S	S	P	S	S	A	A	A	A	A	A	A	A	A	A	M	M	X	K	K	K	K	K	K
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	E	E	I	I	I	P	S	S	S	S	S	S	S	S	A	A	A	A	A	A	A	A	M	M	K	X	K	K	K	K	K	K
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	E	J	I	I	I	P	S	S	S	S	S	S	S	S	A	A	A	A	A	M	M	M	K	K	K	K	K	K	K	K	K
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I	I	I	P	P	P	S	S	S	S	S	S	S	A	M	M	M	M	M	K	K	K	K	K	K	K	K	K	K
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I	I	P	P	P	S	S	S	T	T	T	T	T	M	M	M	M	K	K	K	K	K	K	K	K	K	K	K
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	P	P	Q	T	T	T	T	T	T	M	M	K	K	K	K	K	K	K	K	K	K	K	K
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	X	K	K	K	K	K	K	K	K	K	K	K	K	K
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Q	Q	Q	Q	Q	Q	Q	Q	Q	K	K	K	K	K	K	K	K	K	K	K	K	K	K
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Q	Q	Q	Q	Q	Q	Q	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K

*Symbols correspond to those in Table12-2

Table 12-4 Procedure of Aquifer Allotment to Model Layer

Symbol	0	B	C	A	P	Q	R	W	X	Y	S
Layer 1	10m	20m	TK	0.5*TK	TK	TK	TK	TK	TK	TK	0.75*TK
Layer 2	10m	50m	50m	0.25*TK	TUR	TUR	TUR	0.75*TUR	0.75*TUR	0.75*TUR	0.25*TK
Layer 3	10m	50m	50m	0.25*TK	TLR	TLR	TLR	0.25*TUR	0.25*TUR	0.25*TUR	TLR
Layer 4	10m	100m	100m	TA	TA	0.25*TLM	TA	TA	0.25*TLM	TA	TA
Layer 5	10m	10m	10m	TLM	TLM	0.75*TLM	10m	TLM	0.75*TLM	10m	TLM
Layer 6	10m	10m	10m	-	-	-	-	-	-	-	-

Symbol	T	V	L	M	K	I	J	D	E	G	H
Layer 1	0.75*TK	0.75*TK	0.75*TK	0.5*TK	TK	0.25*TUR	0.25*TUR	0.25*TUR	0.25*TUR	0.25*TLR	0.125*TLM
Layer 2	0.25*TK	0.25*TK	0.25*TK	0.25*TK	10m	0.75*TUR	0.75*TUR	0.5*TUR	0.5*TUR	0.25*TLR	0.125*TLM
Layer 3	TLR	TLR	TLR	0.25*TK	10m	TLR	TLR	0.25*TUR	0.25*TUR	0.5*TLR	0.125*TLM
Layer 4	0.25*TLM	TA	10m	0.25*TLM	10m	TA	0.25*TLM	TA	0.25*TLM	TA	0.125*TLM
Layer 5	0.75*TLM	10m	10m	0.75*TLM	10m	TLM	0.75*TLM	TLM	0.75*TLM	TLM	0.5*TLM
Layer 6	-	-	10m	-	10m	-	-	-	-	-	-

*) TK: Thickness of Kalahari Beds
TUR: Thickness of Upper Rietmond Member
TLR: Thickness of Lower Rietmond Member
TA: Thickness of Auob Aquifer
TLM: Thickness of Lower Mukorob Member
**) Symbols correspond to those in Table12-2 and Table12-3.

Table 12-5 Bottom Elevation of Model Layer 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1864	1815	1844	1740	1675	1638	1621	1591	1554	1534	1516	1506	1520	1558	1525	1486	1486	1461	1425	1413	1427	1446	1442	1439	1433	1467	1429	1422	1449	1456	1507	1484	1473	1472	1461	1436	1362	1305	1285	1277	1263	1257	1243	1239	1238	1238	1238	1238
2	1981	1866	1896	1761	1728	1673	1627	1603	1579	1536	1503	1498	1436	1523	1556	1474	1433	1449	1432	1400	1404	1424	1424	1425	1426	1441	1411	1418	1443	1482	1486	1463	1454	1437	1413	1379	1353	1350	1345	1310	1273	1259	1249	1247	1247	1247	1247	1247
3	1909	1855	1799	1729	1687	1636	1606	1578	1553	1535	1503	1485	1473	1513	1490	1427	1402	1405	1427	1402	1382	1395	1398	1405	1415	1414	1390	1416	1433	1444	1447	1439	1424	1402	1392	1358	1343	1337	1318	1299	1285	1275	1265	1255	1256	1256	1256	1256
4	1833	1811	1778	1759	1714	1646	1592	1555	1547	1549	1543	1476	1454	1459	1465	1419	1403	1387	1402	1406	1392	1368	1378	1389	1394	1395	1373	1404	1430	1433	1424	1405	1388	1376	1370	1364	1343	1312	1299	1289	1280	1273	1266	1259	1259	1259	1259	1259
5	1808	1764	1720	1712	1650	1629	1572	1565	1585	1582	1492	1479	1468	1442	1450	1423	1385	1371	1378	1385	1379	1360	1371	1380	1383	1370	1370	1406	1420	1430	1420	1401	1384	1366	1354	1342	1321	1302	1288	1279	1268	1260	1261	1260	1260	1260	1260	1260
6	1880	1796	1852	1689	1606	1641	1645	1668	1555	1509	1459	1469	1464	1448	1449	1410	1384	1362	1357	1365	1357	1338	1354	1355	1350	1358	1374	1390	1390	1425	1440	1410	1380	1359	1339	1327	1318	1299	1288	1280	1270	1265	1250	1230	1230	1230	1230	1230
7	1715	1838	1814	1684	1621	1575	1649	1542	1474	1459	1447	1448	1441	1450	1454	1401	1387	1372	1358	1339	1339	1334	1350	1334	1343	1354	1370	1375	1380	1420	1430	1400	1360	1350	1326	1315	1312	1293	1280	1265	1245	1235	1220	1212	1212	1212	1212	1212
8	1606	1758	1720	1729	1635	1578	1495	1490	1445	1434	1436	1428	1420	1426	1413	1389	1378	1367	1351	1335	1319	1322	1334	1326	1355	1363	1365	1365	1380	1395	1420	1390	1300	1340	1290	1280	1280	1280	1270	1245	1240	1215	1203	1160	1160	1160	1160	1160
9	1561	1608	1589	1528	1504	1453	1448	1465	1431	1454	1425	1413	1429	1401	1392	1377	1362	1352	1340	1333	1325	1300	1305	1301	1321	1329	1356	1360	1390	1410	1411	1385	1340	1335	1310	1280	1260	1255	1245	1255	1255	1210	1200	1240	1240	1240	1240	1240
10	1471	1532	1477	1471	1451	1431	1437	1427	1447	1419	1428	1416	1408	1374	1371	1369	1360	1349	1341	1332	1318	1335	1286	1250	1306	1300	1340	1332	1340	1340	1393	1380	1350	1320	1310	1290	1220	1200	1225	1255	1240	1200	1200	1230	1230	1230	1230	1230
11	1448	1452	1441	1425	1421	1423	1423	1434	1424	1451	1442	1409	1362	1358	1352	1345	1344	1332	1320	1315	1308	1300	1245	1250	1275	1280	1300	1335	1330	1312	1310	1365	1340	1290	1300	1275	1200	1190	1220	1220	1175	1199	1196	1247	1247	1247	1247	1247
12	1412	1416	1412	1432	1424	1432	1501	1408	1435	1395	1371	1366	1342	1340	1336	1331	1324	1315	1309	1304	1302	1298	1250	1245	1265	1288	1303	1312	1351	1301	1270	1310	1320	1280	1270	1260	1220	1170	1160	1192	1222	1224	1225	1228	1228	1228	1228	1228
13	1376	1358	1370	1393	1371	1429	1424	1419	1389	1361	1355	1355	1347	1342	1336	1327	1317	1307	1301	1294	1298	1255	1245	1230	1270	1278	1288	1297	1320	1320	1250	1275	1260	1265	1260	1230	1170	1140	1223	1219	1220	1213	1217	1219	1219	1219	1219	1219
14	1351	1353	1391	1369	1356	1339	1393	1349	1354	1357	1354	1349	1339	1335	1327	1322	1315	1305	1300	1294	1250	1240	1230	1220	1240	1270	1275	1286	1270	1281	1260	1240	1240	1240	1235	1220	1200	1184	1150	1160	1225	1204	1203	1220	1220	1220	1220	1220
15	1329	1324	1318	1317	1325	1319	1309	1313	1341	1350	1347	1342	1327	1318	1317	1310	1306	1300	1295	1290	1245	1240	1215	1210	1225	1265	1275	1280	1260	1265	1260	1250	1245	1240	1230	1225	1220	1210	1205	1205	1205	1217	1232	1239	1239	1239	1239	1239
16	1317	1307	1302	1301	1305	1302	1298	1299	1323	1339	1345	1334	1320	1311	1310	1305	1290	1290	1291	1284	1250	1255	1220	1210	1225	1240	1260	1270	1251	1245	1259	1250	1245	1235	1235	1230	1225	1220	1210	1210	1210	1200	1195	1210	1210	1210	1210	1210
17	1318	1302	1294	1292	1295	1294	1294	1295	1306	1333	1334	1324	1310	1306	1301	1291	1281	1281	1282	1230	1250	1245	1225	1216	1200	1225	1250	1260	1246	1245	1240	1245	1240	1235	1230	1225	1225	1225	1220	1220	1220	1215	1210	1220	1220	1220	1220	1220
18	1320	1296	1283	1281	1282	1295	1273	1276	1297	1322	1314	1311	1275	1275	1275	1275	1275	1270	1265	1260	1255	1234	1230	1203	1194	1220	1225	1220	1241	1238	1235	1234	1230	1230	1230	1225	1225	1220	1220	1220	1215	1210	1200	1205	1205	1205	1205	1205
19	1332	1296	1276	1269	1269	1268	1260	1265	1281	1300	1297	1282	1240	1240	1240	1240	1240	1255	1245	1250	1220	1206	1205	1220	1180	1190	1185	1200	1230	1235	1229	1226	1225	1220	1220	1220	1220	1210	1210	1210	1210	1205	1180	1170	1170	1170	1170	1170
20	1335	1299	1270	1256	1245	1248	1248	1256	1271	1287	1288	1279	1250	1269	1261	1255	1251	1250	1220	1195	1198	1195	1220	1220	1175	1160	1175	1210	1220	1215	1200	1210	1210	1210	1210	1210	1210	1200	1190	1180	1180	1175	1160	1100	1100	1100	1100	1100
21	1339	1303	1255	1236	1234	1237	1235	1242	1254	1251	1287	1277	1260	1255	1245	1240	1235	1225	1195	1180	1190	1220	1200	1170	1140	1150	1180	1205	1200	1140	1150	1180	1200	1205	1205	1205	1200	1180	1200	1190	1170	1120	1075	1070	1070	1070	1070	1070
22	1330	1310	1268	1230	1226	1225	1223	1225	1236	1239	1260	1257	1250	1240	1235	1230	1220	1200	1195	1175	1195	1195	1200	1150	1135	1140	1170	1190	1155	1120	1120	1150	1170	1180	1190	1180	1175	1165	1130	1160	1140	1050	1030	1050	1050	1050	1050	1050
23	1307	1306	1264	1246	1222	1222	1222	1219	1223	1223	1235	1245	1241	1235	1230	1225	1230	1180	1160	1160	1220	1200	1160	1140	1145	1150	1100	1150	1140	1070	1120	1150	1135	1120	1110	1120	1125	1140	1090	1060	1040	980	1010	1020	1020	1020	1020	1020
24	1299	1274	1263	1263	1223	1219	1218	1219	1217	1219	1220	1233	1236	1219	1223	1210	1218	1210	1170	1140	1190	1205	1203	1202	1200	1170	1070	1120	1040	1030	1100	1110	1120	1090	1075	1090	1100	1070	1120	1050	1076	945	1000	990	990	990	990	990
25	1311	1268	1252	1253	1237	1235	1205	1204	1205	1210	1217	1224	1224	1208	1193	1192	1190	1195	1205	1180	1157	1170	1207	1203	1180	1150	1132	1159	1107	1110	1133	1045	1055	1050	1080	1110	1130	1110	1000	1071	1069	970	1025	1050	1050	1050	1050	1050
26	1275	1266	1229	1243	1243	1236	1198	1202	1198	1204	1230	1209	1200	1210	1195	1206	1195	1190	1185	1185	1181	1150	1135	1130	1180	1178	1123	1162	1172	1095	1115	1114	1120	1122	1080	1120	1070	1120	1102	1067	1020	1050	1070	1080	1080	1080	1080	1080
27	1252	1240	1213	1218	1216	1219	1193	1194	1194	1195	1221	1202	1210	1200	1199	1200	1200	1190	1180	1165	1155	1151	1155	1126	1181	1169	1132	1098	1146	1097	1090	1105	1109	1115	1121	1070	1064	1064	1061	950	945	1000	1060	1100	1100	1100	1100	1100
28	1277	1254	1227	1206	1198	1200	1204	1194	1189	1191	1196	1201	1200	1200	1198	1186	1190	1175	1165	1155	1167	1173	1169	1111	1179	1173	1138	1096	1111	1102	1068	1089	1097	1102	1099	1036	1055	1055	1053	940	1050	1060	1070	1080	1080	1080	1080	1080
29	1307	1276	1251	1223	1203	1193	1186	1177	1180	1193	1193	1195	1211	1190	1180	1172	1160	1155	1150	1169	1158	1158	1168	1156	1150	1178	1161	1119	1080	1073	1062	1000	1063	1091	1079	1053	1052	1050	1054	970	1050	1060	1065	1050	1050	1050	1050	1050
30	1291	1265	1251	1215	1203	1204	1196	1158	1170	1172	1182	1187	1199	1185	1180	1175	1165	1155	1155	1153	1151	1148	1135	1086	1146	1173	1174	1140	1091	1059	1050	1066	1061	1072	1067	1047	1048	950	1010	1050	1050	1045	1050	1040	1040	1040	1040	1040
31	1283	1273	1235	1217	1212	1215	1193	1173	1161	1174	1172	1176	1200	1185	1180	1175	1165	1163	1164	1145	1135	1138	1125	1083	1080	1155	1167	1150	1112	1061	1042	1057	1049	1051	1041	1036	940	970	1030	1050	1040	1030	1030	1020	1020	1020	1020	1020
32	1300	1258	1243	1245	1233	1248	1231	1204	1151	1148	1130	1157	1190	1185	1180	1175	1170	1170	1154	1140	1130	1115	1100	1035	1120	1122	1146	1133	1114	1054	1023	1039	1052	1044	1040	1035	1039	980	1015	1030	1025	1010	1000	1000	1000	1000	1000	1000
33	1295	1270	1279	1250	1198	1243	1243	1228	1169	1139	1098	1127	1190	1185	1180	1175	1170	1165	1162	1135	1125	1175	1105	1025	990	1076	1083	1093	1105	1044	1022	1038	991	990	1033	1036	1045	990	1010	1010	1010	1015	1000	990	990	990	990	990
34	1302	1257	1243	1208	1177	1194	1187	1174	1170	1133	1102	1105	1171	1161	1180	1170	1160	1165	1165	1145	1130	1120	1110	1070	1020	1069	1069	1092	1093	1036	1022	1039	1037	1038	1030	1040	1045	980	990	990	990	1010	990	985	985	985	985	985
35	1275	1245	1234	1204	1183	1194	1175	1159	1142	1117	1099	1105	1185	1180	1178	1160	1140	1145	1160	1155	1130	1120	1115	1090	1030	1066	1076	1081	1074	1034	1013	1041	1039	1023	1025	1038	970	930	980	980	990	990	985	980	980	980	980	980
36	1246	1218	1219	1220	1207	1176	1143	1119	1108	1103	1095	1161	1193	1197	1197	1175	1160	1150	1150	1155	1120	1110	1100	1105	1000	1058	1062	1059	1031	1012	1004	1010	1028	1014	1020	950	960	960	965	970	970	970	975	980	980	980	980	990
37	1222	1199	1186	1185	1173	1156	1099	1059	1088	1094	1087	1161	1192	1197	1210	1200	1175	1160	1140	1140	1120	1070	1030	1000	970	1039	1044	1040	1030	1008	1002	1006	1007	962	910	940	955	945	955	960	960	960	965	980	980	980	980	980
38	1218	1201	1190	1164	1143	1144	1077	1038	1102	1077	1086	1184	1189	1189.	1210	1200	1180	1165	1150	1130	1110	1050	1020	975	1030	1029	1039	1032	1021	1011	1001	1010	1006	1006	1010	950	950	940	950	950	945	955	960	965	965	965	965	965
39	1271	1291	1303	1244	1127	1117	1054	1045	1067	1074	1087	1183	1189	1185	1185	1180	1170	1160	1150	1120	1060	1035	1020	1056	1017	1039	1039	1030	1018	1010	958	1007	1019	930	935	955	950	940	940	935	935	940	950	955	955	955	955	955
40	1274	1322	1323	1253	1148	1095	1025	1078	1067	1074	1094	1177	1179	1178	1175	1170	1150	1130	1120	1085	1065	1040	1087	1058	1016	960	980	940	930	1006	990	1001	1014	955	955	960	940	945	945	940	940	930	950	960	960	960	960	960
41	1299	1281	1332	1234	1106	1051	1032	1078	1043	1057	1100	1170	1171	1168	1171	1178	1135	1110	1112	1094	1068	1060	1089	1055	957	1002	1000	970	978	963	938	1001	930	955	950	945	950	960	955	950	910	925	945	955	955	955	955	955
42	1355	1330	1245	1170	1096	1022	1058	1051	1034	1061	1117	1165	1164	1161	1160	1167	1120	1112	1103	1064	1064	1050	1018	985	958	970	1006	998	979	967	943	948	930	920	930	935	940	960	980	950	900	920	940	960	960	960	960	960
43	1406	1321	1269	1134	1085	996	1037	1037	1067	1055	1097	1154	1155	1145	1147	1150	1125	1110	1110	1090	1055	1026	1001	975	958	949	983	991	986	969	943	935	950	944	948	920	930	940	960	930	890	910	940	955	955	955	955	955
44	1395	1294	1203	1129	1046	990	994	1049	1067	1044	1061	1143	1105	1101	1137	1155	1140	1130	1120	1093	1053	1018	1004	981	967	945	960	1030	1027	1027	945	932	931	930	931	934	920	945	940	920	895	930	955	960	960	960	960	960
45	1367	1292	1196	1134	1067	992	995	1027	1061	1034	1041	1105	1077	1074	1102	1154	1140	1129	1100	1091	1078	1058	1029	1011	978	961	940	1035	1017	1015	933	975	961	954	955	974	885	920	930	900	860	920	950	960	960	960	960	960
46	1365	1325	1201	1139	1081	994	990	994	1053	1032	1015	1053	1009	1060	1074	1125	1140	1119	1088	1067	1061	1059	1043	1018	996	960	951	990	1003	1013	1008	970	950	946	948	967	890	920	943	880	880	940	950	945	945	945	945	945
47	1374	1271	1191	1132	1085	995	964	975	1044	1025	1000	1008	1033	1072	1053	1085	1135	1126	1101	1083	1057	1054	1044	1028	1003	974	969	999	988	997	998	961	933	932	950	966	979	930	915	850	900	940	935	930	930	930	930	930
48	1368	1228	1164	1145	1091	1009	970	975	999	1026	995	992	1007	1023	1049	1083	1121	1120	1105	1089	1072	1056	1047	1037	1029	996	950	996	1000	985	968	963	925	921	935	870	905	910	919	859	890	925	910	920	920	920	920	920
49	1356	1219	1135	1137	1125	1016	978	970	991	1030	993	975	986	1010	1072	1104	1100	1079	1064	1083	1060	1055	1046	1044	1020	1015	980	999	935	933	985	984	979	946	924	869	905	927	893	850	881	910	921	900	900	900	900	900
50	1333	1222	1135	1108	1101	1001	993	964	992	1002	984	965	983	994	1009	1095	1073	1067	1048	1036	1091	1050	1040	1043	1035	1015	980	1006	995	989	987	984	980	968	948	930	852	866	857	848	876	903	906	880	880	880	880	880
51	1345	1237	1153	1113	1083	1003	981	968	967	982	979	955	957	973	997	1072	1079	1068	1041	1052	1085	1073	1064	1051	1025	1010	990	970	937	989	986	986	993	978	959	942	915	908	906	843	868	850	860	903	903	903	903	903
52	1323	1247	1161	1120	1089	1016	985	977	977	975	979	950	947	981	997	1059	1065	1076	1050	1059	1086	1072	1062	1053	1038	1027	1005	998	971	992	983	983	984	981	970	945	926	911	902	897	904	835	840	860	860	860	860	860
53	1322	1216	1161	1117	1103	1032	997	977	975	987	956	946	939	967	1007	1004	1038	1064	1066	1071	1081	1055	1061	1057	1043	1024	1007	934	982	965	986	980	986	977	968	949	930	915	904	895	790	815	830	840	840	840	840	840
54	1321	1249	1169	1145	1102	1029	997	1022	1197	1004	962	947	933	955	991	993	1007	1031	1050	1051	1062	1057	1060	1062	1048	1030	1017	997	985	979	963	981	978	976	967	948	932	919	905	780	765	800	820	830	830	830	830	830
55	1303	1244	1194	1152	1115	1031	1001	950	1031	962	935	930	931	956	990	979	968	1006	1034	1037	1045	1048	1060	1055	1045	1028	1011	990	985	974	966	961	973	971	964	950	932	922	810	790	775	790	810	820	820	820	820	820
56	1314	1240	1165	1164	1139	1047	980	942	921	923	916	925	935	964	972	965	981	1002	1038	1042	1010	1010	1044	1040	1030	1021	1010	996	990	976	977	962	954	963	960	948	931	825	815	765	770	785	805	815	815	815	815	815
57	1327	1234	1198	1191	1150	1063	959	920	919	917	920	912	924	942	946	955	978	1021	1040	1031	1015	1026	1015	1029	1039	1027	1025	1010	994	1004	960	955	957	939	950	939	842	820	817	765	769	762	797	806	806	806	806	806
58	1302	1237	1216	1168	1152	1066	950	920	918	901	901	911	925	935	949	963	1014	1024	1024	1023	1017	1027	1012	1012	1031	1029	1029	1016	982	990	971	955	952	923	896	857	839	823	819	782	766	781	802	808	808	808	808	808
59	1276	1232	1220	1203	1155	1056	941	912	908	885	908	928	960	961	997	1016	1003	1024	1057	1043	1065	1056	1034	1011	1015	1014	1017	1011	999	992	977	953	942	924	907	857	821	820	813	781	762	779	799	808	808	808	808	808
60	1287	1222	1208	1176	1140	1072	924	897	872	893	940	954	994	1020	1049	1084	1045	1048	1069	1078	1096	1079	1053	1022	1000	987	991	980	979	986	976	955	941	917	903	865	806	818	811	783	766	778	798	808	808	808	808	808

Table 12-6 Bottom Elevation of Model Layer 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1854	1805	1834	1730	1665	1628	1611	1581	1544	1524	1506	1498	1510	1548	1515	1478	1476	1451	1415	1403	1417	1438	1432	1429	1423	1457	1419	1412	1439	1456	1497	1474	1463	1462	1451	1426	1352	1295	1275	1267	1253	1241	1233	1228	1228	1228	1228	1228
2	1971	1858	1886	1751	1718	1663	1617	1593	1569	1526	1493	1478	1486	1513	1548	1464	1423	1439	1422	1390	1394	1414	1414	1415	1416	1431	1401	1408	1433	1472	1476	1453	1444	1427	1403	1369	1343	1340	1335	1300	1283	1249	1239	1237	1237	1237	1237	1237
3	1899	1845	1788	1719	1677	1628	1596	1568	1543	1525	1493	1476	1463	1503	1480	1417	1392	1398	1417	1392	1372	1385	1388	1395	1405	1404	1380	1406	1423	1434	1437	1429	1414	1392	1372	1348	1333	1327	1308	1288	1275	1265	1255	1246	1248	1246	1246	1246
4	1823	1801	1768	1749	1704	1636	1582	1545	1537	1539	1533	1468	1484	1449	1455	1409	1393	1377	1392	1398	1382	1358	1368	1379	1384	1385	1363	1394	1420	1423	1414	1398	1378	1366	1360	1354	1333	1302	1289	1279	1270	1263	1256	1249	1249	1249	1249	1249
5	1798	1754	1710	1702	1650	1619	1582	1555	1575	1572	1482	1469	1458	1432	1440	1413	1375	1361	1368	1375	1369	1350	1361	1370	1373	1360	1380	1398	1368	1370	1330	1400	1383	1356	1344	1332	1311	1292	1278	1269	1258	1250	1251	1250	1250	1250	1250	1250
6	1870	1788	1842	1679	1598	1631	1635	1658	1545	1498	1449	1459	1454	1438	1439	1400	1374	1352	1347	1355	1347	1328	1344	1345	1340	1348	1364	1353	1353	1361	1340	1407	1370	1349	1329	1317	1306	1289	1278	1270	1260	1255	1240	1220	1220	1220	1220	1220
7	1705	1828	1804	1674	1611	1565	1638	1532	1464	1446	1437	1438	1431	1440	1424	1391	1377	1382	1348	1329	1329	1324	1340	1324	1333	1344	1346	1349	1380	1355	1300	1250	1255	1275	1320	1310	1310	1253	1235	1216	1196	1170	1190	1190	1190	1190	1190	1190
8	1596	1748	1710	1719	1625	1568	1485	1480	1435	1424	1426	1418	1410	1416	1403	1379	1368	1357	1341	1325	1309	1312	1324	1316	1345	1360	1350	1325	1365	1330	1275	1290	1265	1290	1275	1270	1250	1235	1218	1196	1184	1160	1180	1150	1150	1150	1150	1150
9	1571	1598	1578	1518	1494	1443	1438	1455	1421	1444	1415	1403	1419	1391	1382	1367	1352	1342	1330	1323	1315	1290	1295	1291	1311	1315	1330	1310	1340	1320	1300	1315	1305	1285	1275	1260	1235	1195	1196	1191	1184	1145	1165	1140	1140	1140	1140	1140
10	1461	1522	1467	1461	1441	1421	1427	1417	1437	1409	1418	1408	1398	1384	1361	1359	1350	1339	1331	1322	1308	1295	1276	1240	1300	1280	1310	1320	1315	1310	1310	1315	1310	1280	1275	1245	1200	1185	1180	1175	1170	1150	1160	1160	1160	1160	1160	1160
11	1438	1442	1431	1415	1411	1413	1413	1424	1414	1441	1432	1399	1352	1348	1342	1335	1334	1322	1310	1305	1298	1290	1235	1235	1240	1260	1290	1320	1290	1290	1290	1290	1295	1280	1265	1225	1165	1160	1180	1170	1160	1160	1160	1224	1224	1224	1224	1224
12	1402	1406	1402	1422	1414	1422	1491	1398	1425	1385	1361	1356	1332	1330	1328	1321	1314	1305	1299	1294	1292	1288	1228	1215	1220	1235	1260	1300	1290	1280	1260	1270	1260	1235	1210	1180	1155	1150	1155	1150	1181	1189	1198	1204	1204	1204	1204	1204
13	1366	1348	1360	1383	1361	1419	1414	1409	1379	1351	1345	1345	1337	1332	1326	1317	1307	1297	1291	1284	1278	1205	1200	1200	1210	1225	1276	1290	1290	1280	1245	1235	1215	1190	1180	1160	1140	1110	1181	1179	1185	1179	1168	1194	1194	1194	1194	1194
14	1341	1343	1381	1359	1348	1389	1383	1339	1344	1347	1344	1339	1329	1325	1317	1312	1305	1295	1290	1284	1240	1185	1195	1185	1200	1220	1235	1260	1260	1240	1215	1200	1165	1150	1145	1145	1165	1150	1135	1145	1201	1180	1180	1180	1180	1180	1180	1180
15	1319	1314	1308	1307	1315	1309	1299	1303	1331	1340	1337	1332	1317	1308	1301	1300	1298	1290	1285	1280	1235	1180	1185	1190	1185	1215	1210	1215	1210	1195	1185	1155	1145	1155	1150	1170	1185	1180	1160	1156	1185	1200	1220	1230	1230	1230	1230	1230
16	1307	1297	1292	1291	1295	1292	1288	1289	1313	1289	1298	1284	1270	1261	1260	1255	1208	1208	1281	1274	1198	1200	1205	1190	1200	1190	1195	1190	1175	1155	1160	1155	1140	1135	1160	1175	1185	1195	1185	1170	1125	1145	1160	1070	1070	1070	1070	1070
17	1308	1292	1284	1282	1285	1284	1284	1285	1256	1263	1284	1274	1260	1256	1251	1241	1202	1198	1272	1210	1240	1235	1220	1200	1190	1185	1190	1185	1145	1145	1150	1150	1130	1125	1130	1130	1150	1160	1150	1140	1120	1090	1080	1075	1075	1075	1075	1075
18	1310	1286	1273	1271	1272	1275	1223	1226	1247	1272	1264	1261	1225	1225	1225	1225	1195	1220	1215	1215	1225	1225	1220	1185	1180	1185	1160	1140	1135	1130	1130	1155	1115	1110	1110	1110	1110	1115	1130	1090	1085	1075	1050	1050	1050	1050	1050	1050
19	1322	1286	1268	1259	1259	1258	1210	1215	1231	1250	1247	1232	1190	1190	1190	1184	1190	1200	1200	1210	1215	1190	1190	1185	1170	1140	1135	1125	1110	1110	1125	1150	1125	1105	1105	1110	1105	1060	1060	1070	1070	1060	1045	1069	1069	1069	1069	1069
20	1325	1289	1260	1246	1195	1198	1198	1206	1221	1237	1238	1229	1200	1218	1211	1184	1185	1180	1190	1180	1180	1185	1185	1135	1115	1120	1115	1105	1090	1090	1110	1150	1140	1100	1095	1090	1090	1025	1070	1045	1050	1065	1040	1040	1040	1040	1040	1040
21	1329	1293	1205	1186	1184	1187	1185	1192	1204	1201	1237	1227	1210	1205	1195	1176	1165	1165	1170	1165	1155	1150	1135	1125	1105	1095	1095	1085	1085	1085	1110	1120	1105	1095	1085	1075	1065	1045	1040	1063	1058	1045	1023	1035	1035	1035	1035	1035
22	1323	1300	1218	1160	1176	1175	1173	1175	1186	1189	1210	1207	1200	1190	1185	1174	1150	1150	1160	1155	1155	1145	1130	1120	1100	1090	1085	1060	1070	1080	1085	1060	1080	1085	1075	1065	1025	1040	1030	1048	1043	998	1023	1030	1030	1030	1030	1030
23	1297	1298	1274	1196	1172	1172	1172	1169	1173	1173	1165	1195	1191	1185	1178	1165	1145	1140	1140	1140	1140	1130	1125	1120	1105	1085	1070	1060	1055	1050	1040	1020	1025	1065	1020	995	1031	1039	1028	1020	988	976	1005	1005	1005	1006	1005	1005
24	1289	1264	1273	1253	1173	1169	1168	1169	1167	1169	1170	1163	1188	1169	1165	1158	1125	1130	1145	1125	1145	1140	1130	1120	1090	1065	1045	1015	1010	995	1033	1020	1050	1055	1011	1023	1029	1025	1030	990	1013	938	985	983	983	983	983	983
25	1301	1258	1242	1243	1227	1155	1155	1154	1155	1160	1167	1174	1174	1158	1143	1120	1120	1130	1155	1140	1135	1145	1140	1105	1094	1083	1091	1134	1054	1055	1089	1015	1045	1030	1025	1030	1048	1039	963	1008	1004	955	980	983	983	983	983	983
26	1265	1258	1219	1233	1233	1158	1148	1152	1148	1154	1180	1169	1150	1160	1145	1085	1090	1155	1150	1150	1170	1130	1110	1110	1098	1164	1081	1141	1161	1042	1068	1070	1080	1081	1020	1068	1040	1065	1056	1004	953	975	955	975	975	975	975	975
27	1242	1230	1203	1208	1206	1209	1143	1144	1144	1145	1171	1152	1160	1150	1149	1065	1065	1155	1150	1160	1140	1145	1150	1100	1173	1154	1101	1049	1123	1059	1045	1060	1070	1077	1065	1048	1007	1007	1000	931	926	944	964	965	965	965	963	965
28	1267	1254	1217	1196	1168	1190	1194	1144	1139	1141	1146	1151	1150	1150	1148	1136	1145	1150	1140	1130	1150	1160	1155	1080	1170	1181	1109	1048	1070	1061	1019	1049	1080	1063	1059	1058	998	997	994	925	938	933	935	945	945	945	945	945
29	1297	1266	1241	1213	1193	1183	1176	1167	1130	1143	1140	1145	1181	1140	1130	1122	1140	1150	1130	1155	1140	1155	1155	1133	1125	1169	1146	1065	1030	1022	1006	950	1047	1053	1034	996	996	995	1002	925	930	940	934	923	923	923	923	923
30	1271	1255	1241	1205	1193	1194	1186	1148	1160	1122	1132	1137	1149	1135	1130	1125	1120	1130	1150	1140	1135	1130	1090	1050	1123	1164	1167	1120	1051	1004	993	1018	1016	1036	1023	994	994	931	939	945	938	929	938	913	913	913	913	913
31	1273	1263	1225	1207	1202	1205	1183	1163	1151	1164	1162	1166	1150	1135	1130	1141	1130	1150	1155	1125	1120	1120	1105	1050	1000	1143	1161	1140	1086	1011	981	1006	997	1000	993	988	925	925	940	941	935	918	903	893	893	893	893	893
32	1290	1248	1233	1235	1223	1238	1221	1194	1141	1138	1120	1147	1140	1135	1150	1141	1130	1160	1140	1115	1110	1090	1075	1025	980	1098	1133	1116	1092	1002	956	979	1003	992	987	985	994	920	936	940	895	909	895	891	891	891	891	891
33	1285	1260	1268	1240	1188	1233	1233	1218	1159	1129	1088	1117	1140	1135	1158	1135	1125	1140	1150	1100	1070	1045	1030	990	960	1033	1042	1057	1083	992	959	984	940	940	981	988	1002	938	906	935	895	875	865	885	885	885	885	885
34	1292	1247	1233	1198	1167	1184	1177	1164	1160	1123	1092	1095	1168	1155	1165	1140	1110	1120	1100	1095	1065	1040	1010	980	950	1024	1024	1056	1067	983	961	990	989	889	980	998	1005	958	945	915	906	880	860	876	876	878	876	876
35	1285	1235	1224	1194	1173	1174	1165	1149	1132	1107	1089	1098	1183	1165	1170	1140	1115	1115	1100	1090	1060	1035	1000	975	945	1023	1038	1045	1037	982	951	995	994	972	975	997	936	945	943	928	908	893	884	883	883	883	883	883
36	1236	1208	1209	1210	1197	1168	1133	1109	1098	1093	1085	1151	1186	1168	1189	1155	1115	1110	1095	1080	1055	1035	995	970	950	1014	1018	1017	978	951	942	950	979	960	970	920	915	923	916	899	891	891	889	890	890	890	890	890
37	1212	1189	1176	1175	1163	1156	1089	1049	1078	1064	1077	1151	1188	1188	1203	1185	1120	1110	1090	1075	1050	1010	985	965	935	988	995	990	980	949	941	948	951	910	895	899	899	896	891	878	874	885	883	886	886	886	886	886
38	1206	1191	1160	1154	1133	1134	1067	1028	1092	1067	1076	1182	1184	1185	1203	1179	1125	1110	1090	1075	1040	1000	960	935	980	974	989	981	970	956	940	958	953	953	980	905	905	884	875	875	868	873	870	871	871	871	871	871
39	1261	1281	1293	1234	1117	1107	1044	1035	1077	1064	1077	1179	1185	1180	1181	1173	1105	1110	1090	1075	1040	985	945	1013	958	994	992	983	969	960	941	956	974	906	915	921	905	886	880	875	871	869	864	865	865	865	865	865
40	1264	1312	1313	1243	1138	1085	1015	1068	1057	1064	1084	1174	1174	1174	1171	1163	1113	1090	1090	1070	1035	990	1058	1019	958	935	920	900	900	958	935	950	972	875	920	923	903	889	878	873	869	866	868	866	866	866	866	866
41	1289	1271	1322	1224	1096	1041	1022	1068	1033	1047	1090	1168	1168	1164	1185	1166	1109	1090	1090	1070	1065	1055	1064	1017	900	960	960	965	935	815	885	950	885	850	900	920	896	855	869	868	858	858	859	861	861	861	861	861
42	1345	1320	1235	1160	1086	1012	1048	1041	1024	1051	1107	1163	1162	1158	1152	1154	1095	1090	1080	1060	1035	1020	980	940	905	920	970	960	935	920	890	900	885	875	890	925	910	895	885	870	865	850	840	845	845	845	845	845
43	1396	1311	1259	1124	1075	986	1027	1027	1052	1045	1087	1152	1153	1143	1145	1145	1095	1090	1075	1070	1025	990	960	930	910	895	940	955	945	925	890	885	905	895	900	865	860	855	850	845	840	840	850	865	865	865	865	865
44	1385	1284	1193	1119	1038	980	984	1039	1057	1034	1051	1133	1103	1098	1135	1140	1095	1100	1090	1075	1025	980	965	940	925	895	910	993	993	991	895	880	885	880	880	952	860	866	865	856	850	863	880	940	940	940	940	940
45	1357	1282	1186	1124	1057	982	985	1017	1051	1024	1031	1095	1067	1071	1097	1125	1090	1120	1070	1075	1060	1050	1000	980	940	920	890	958	984	982	946	922	906	897	910	924	851	856	859	851	845	875	940	945	945	945	945	945
46	1355	1315	1191	1129	1071	984	980	984	1043	1022	1005	1043	1029	1050	1071	1120	1135	1110	1070	1045	1040	1040	1020	990	965	920	910	940	961	981	979	920	893	888	894	921	853	856	858	850	855	885	935	885	885	885	885	885
47	1364	1261	1181	1122	1075	985	974	965	1034	1015	990	998	1023	1069	1050	1083	1116	1120	1090	1070	1050	1035	1025	1005	975	940	935	960	939	958	964	913	871	871	900	923	944	859	835	843	870	870	870	890	890	890	890	890
48	1358	1218	1154	1136	1081	999	960	965	989	1016	985	982	997	1013	1046	1081	1109	1095	1100	1060	1060	1040	1030	1020	1010	970	940	963	960	940	919	911	880	855	883	855	870	895	880	800	875	875	870	880	880	880	880	880
49	1346	1209	1125	1127	1115	1006	968	960	981	1020	983	965	976	1000	1069	1102	1085	1080	1046	1070	1050	1040	1030	1030	1015	965	940	970	962	954	948	947	939	891	859	810	860	890	850	785	850	905	890	870	870	870	870	870
50	1323	1212	1125	1098	1091	991	983	954	982	992	974	956	970	984	998	1079	1065	1065	1035	1016	1070	1045	1035	1030	1020	965	950	984	965	957	953	950	945	927	899	875	790	810	800	790	830	870	870	860	860	860	860	860
51	1335	1227	1143	1103	1073	993	971	958	957	972	969	945	947	963	987	1057	1050	1055	1031	1037	1080	1060	1055	1040	1020	990	960	950	968	959	955	953	949	944	919	896	857	849	848	785	820	825	800	870	870	870	870	870
52	1313	1237	1151	1110	1079	1006	975	967	967	965	969	940	937	971	987	1048	1040	1045	1050	1055	1065	1060	1050	1040	1025	1015	990	980	945	966	957	954	952	948	937	903	875	853	844	838	852	820	830	850	850	850	850	850
53	1312	1206	1151	1107	1093	1022	987	967	965	977	946	936	928	957	997	994	1033	1005	1020	1040	1045	1045	1050	1045	1030	1010	990	975	980	940	960	955	956	948	937	910	882	863	847	838	780	805	820	830	830	830	830	830
54	1311	1239	1179	1135	1092	1019	987	1012	1187	994	952	937	923	945	981	980	997	977	955	995	1015	1025	1045	1055	1040	1020	1005	980	985	960	940	958	952	945	938	909	886	889	853	770	775	790	810	820	820	820	820	820
55	1293	1234	1184	1142	1105	1021	991	970	1021	952	926	920	921	946	970	969	978	996	1024	930	970	995	1005	980	1000	1020	1000	980	970	965	950	940	952	946	935	912	886	874	800	780	765	780	800	810	810	810	810	810
56	1304	1230	1176	1174	1129	1037	970	932	911	913	906	916	926	954	962	956	971	992	1028	1032	900	915	910	910	810	1015	1000	985	975	970	965	945	935	939	933	911	888	815	805	775	760	775	795	805	805	805	805	805
57	1317	1224	1188	1181	1140	1053	959	910	909	907	910	902	914	932	936	945	968	1011	1030	1021	1005	1016	1005	880	890	1010	995	985	981	996	968	938	938	915	923	902	832	810	807	775	758	772	787	796	798	796	796	796
58	1292	1227	1206	1178	1142	1056	940	910	908	891	891	901	916	926	939	953	1004	1014	1014	1013	1007	1017	1002	1002	870	950	940	950	960	950	925	915	890	865	862	847	828	813	809	772	756	771	792	798	798	798	798	798
59	1266	1222	1210	1193	1145	1046	931	902	898	875	898	916	950	971	987	1006	993	1014	1047	1033	1055	1056	1024	1001	1005	920	910	910	920	915	900	895	870	855	897	847	811	810	803	771	752	769	789	798	798	798	798	798
60	1277	1212	1198	1166	1130	1062	914	887	882	883	930	944	984	1010	1039	1074	1035	1038	1059	1068	1066	1069	1043	1012	990	977	880	865	885	880	875	870	845	907	893	855	796	808	801	773	756	768	788	798	798	798	798	798

Table 12-7 Bottom Elevation of Model Layer 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1844	1795	1824	1720	1655	1618	1601	1571	1534	1514	1496	1466	1500	1538	1505	1466	1466	1441	1405	1393	1407	1426	1422	1419	1413	1447	1409	1402	1429	1446	1487	1464	1453	1452	1441	1416	1342	1285	1265	1257	1243	1231	1223	1218	1218	1218	1218	1218
2	1961	1846	1876	1741	1708	1653	1607	1583	1559	1516	1483	1468	1476	1503	1536	1454	1413	1429	1412	1380	1384	1404	1404	1405	1406	1421	1391	1398	1423	1462	1466	1443	1434	1417	1393	1359	1333	1330	1325	1290	1253	1239	1229	1227	1227	1227	1227	1227
3	1869	1835	1778	1709	1667	1616	1586	1558	1533	1515	1483	1465	1453	1493	1470	1407	1382	1386	1407	1392	1362	1375	1378	1365	1395	1394	1370	1396	1413	1424	1427	1419	1404	1382	1362	1339	1323	1317	1298	1278	1265	1255	1245	1236	1236	1236	1236	1236
4	1813	1791	1758	1739	1694	1626	1572	1535	1527	1529	1523	1456	1474	1439	1445	1399	1383	1367	1382	1386	1372	1348	1358	1369	1374	1375	1353	1384	1410	1413	1404	1386	1368	1358	1350	1344	1323	1292	1279	1269	1260	1253	1246	1239	1239	1239	1239	1239
5	1788	1744	1700	1692	1640	1609	1552	1545	1565	1562	1472	1459	1446	1422	1430	1403	1365	1351	1358	1365	1359	1340	1351	1360	1363	1350	1350	1386	1350	1350	1300	1350	1378	1346	1334	1322	1301	1282	1268	1259	1248	1240	1241	1240	1240	1240	1240	1240
6	1860	1776	1832	1669	1586	1621	1625	1648	1535	1488	1439	1449	1444	1428	1429	1390	1364	1342	1337	1345	1337	1318	1334	1335	1330	1338	1354	1340	1340	1340	1300	1377	1360	1339	1319	1307	1296	1279	1268	1260	1250	1245	1230	1210	1210	1210	1210	1210
7	1695	1618	1794	1664	1601	1555	1628	1522	1454	1438	1427	1428	1421	1430	1414	1361	1367	1352	1339	1319	1319	1314	1330	1314	1323	1334	1340	1340	1330	1325	1270	1240	1240	1255	1310	1300	1305	1253	1235	1216	1196	1165	1160	1145	1145	1145	1145	1145
8	1586	1738	1700	1709	1615	1558	1475	1470	1425	1414	1416	1408	1400	1406	1393	1369	1358	1347	1331	1315	1299	1302	1314	1306	1335	1355	1330	1320	1310	1280	1250	1260	1255	1260	1260	1255	1240	1220	1200	1180	1165	1150	1140	1135	1135	1135	1135	1135
9	1561	1598	1568	1509	1484	1433	1428	1445	1417	1434	1405	1393	1409	1381	1372	1357	1342	1332	1320	1313	1305	1280	1295	1261	1301	1300	1290	1285	1280	1270	1270	1255	1255	1255	1255	1240	1220	1190	1180	1170	1160	1140	1120	1115	1115	1115	1115	1115
10	1451	1512	1457	1451	1431	1411	1417	1407	1427	1399	1408	1396	1388	1354	1351	1349	1340	1329	1321	1312	1298	1285	1266	1230	1295	1260	1270	1260	1250	1260	1260	1250	1255	1230	1240	1220	1180	1165	1160	1145	1140	1125	1110	1090	1090	1090	1090	1090
11	1429	1432	1421	1405	1401	1403	1403	1414	1404	1431	1422	1369	1342	1338	1332	1325	1324	1312	1300	1295	1288	1280	1275	1230	1230	1240	1250	1265	1240	1235	1230	1240	1240	1220	1210	1175	1140	1135	1130	1120	1120	1120	1110	1230	1200	1200	1200	1200
12	1392	1396	1392	1412	1404	1412	1481	1398	1415	1375	1351	1346	1322	1320	1316	1311	1304	1295	1289	1284	1282	1278	1270	1210	1210	1220	1240	1260	1235	1220	1200	1210	1200	1175	1150	1125	1100	1100	1100	1100	1140	1155	1170	1180	1180	1180	1180	1180
13	1356	1338	1350	1373	1351	1409	1404	1399	1369	1341	1335	1335	1327	1322	1316	1307	1297	1287	1281	1274	1268	1200	1130	1185	1190	1200	1225	1235	1225	1190	1175	1170	1150	1130	1120	1100	1085	1090	1140	1140	1150	1145	1160	1170	1170	1170	1170	1170
14	1331	1333	1371	1349	1338	1379	1373	1329	1334	1337	1334	1329	1319	1315	1307	1302	1295	1285	1280	1274	1230	1180	1180	1175	1175	1180	1180	1200	1195	1170	1150	1135	1100	1090	1090	1090	1155	1130	1130	1140	1175	1130	1110	1130	1130	1130	1130	1130
15	1309	1304	1298	1297	1305	1299	1269	1293	1321	1330	1327	1322	1307	1298	1291	1290	1286	1280	1275	1270	1225	1175	1170	1170	1160	1160	1150	1150	1140	1130	1120	1090	1060	1100	1130	1140	1155	1155	1155	1140	1110	1100	1120	1030	1030	1030	1030	1030
16	1297	1287	1282	1281	1285	1282	1278	1279	1303	1239	1246	1234	1220	1211	1210	1205	1180	1180	1271	1264	1175	1170	1165	1140	1150	1140	1145	1140	1120	1090	1085	1080	1070	1080	1110	1125	1130	1140	1130	1120	1080	1070	1060	1050	1050	1050	1050	1050
17	1298	1282	1274	1272	1275	1274	1274	1275	1206	1233	1234	1224	1210	1206	1201	1191	1175	1170	1262	1155	1170	1165	1160	1140	1150	1155	1150	1100	1085	1075	1070	1065	1060	1060	1070	1070	1090	1100	1090	1080	1070	1060	1060	1060	1060	1060	1060	1060
18	1300	1276	1263	1261	1262	1265	1173	1176	1197	1222	1214	1211	1175	1175	1175	1175	1170	1165	1160	1160	1160	1160	1155	1125	1120	1125	1100	1080	1070	1060	1050	1045	1045	1040	1040	1045	1045	1050	1070	1060	1060	1055	1045	1040	1040	1040	1040	1040
19	1312	1276	1256	1249	1249	1248	1160	1165	1181	1200	1197	1182	1140	1140	1140	1165	1160	1150	1155	1155	1150	1125	1125	1120	1110	1080	1075	1065	1045	1040	1040	1040	1040	1035	1035	1040	1040	1040	1040	1050	1055	1050	1040	1035	1035	1035	1035	1035
20	1315	1279	1250	1236	1145	1148	1148	1156	1171	1187	1188	1179	1150	1168	1161	1160	1155	1140	1135	1125	1115	1120	1100	1070	1050	1055	1050	1040	1025	1020	1025	1030	1035	1030	1030	1025	1030	1020	1030	1040	1045	1050	1035	1020	1020	1020	1020	1020
21	1319	1283	1155	1136	1134	1137	1135	1142	1154	1151	1187	1177	1160	1155	1145	1155	1150	1135	1120	1110	1090	1085	1070	1060	1040	1035	1030	1020	1010	1005	1010	1020	1030	1025	1020	1015	1010	1005	1020	1020	1020	1070	1005	1030	1030	1030	1030	1030
22	1313	1290	1168	1130	1126	1125	1123	1125	1135	1139	1160	1157	1150	1140	1135	1155	1140	1125	1115	1100	1090	1080	1070	1060	1040	1030	1020	990	990	1000	1010	1015	1020	1020	1015	1010	990	1010	1010	1010	1010	980	1020	1025	1025	1025	1025	1025
23	1287	1286	1264	1146	1122	1122	1122	1119	1123	1123	1135	1145	1141	1135	1160	1145	1135	1120	1110	1090	1080	1070	1065	1060	1050	1030	1010	990	985	995	1010	1015	1020	1015	1010	990	1000	1005	1005	1000	970	975	1000	1000	1000	1000	1000	1000
24	1279	1254	1263	1243	1123	1119	1118	1119	1117	1119	1120	1133	1136	1119	1145	1140	1115	1115	1120	1090	1085	1080	1070	1065	1060	1040	1020	995	985	990	1010	1015	1020	1010	990	1000	1005	1010	1000	970	950	935	980	980	980	980	980	980
25	1291	1248	1232	1233	1217	1105	1105	1104	1105	1110	1117	1124	1124	1108	1093	1115	1110	1115	1135	1110	1075	1085	1080	1070	1065	1060	1050	1110	1000	1000	1045	1010	1020	1020	1070	1020	1020	1015	950	945	940	950	965	950	960	960	960	960
26	1255	1246	1209	1223	1223	1106	1098	1102	1098	1104	1100	1109	1100	1110	1095	1090	1080	1140	1130	1120	1110	1070	1050	1075	1070	1150	1040	1120	1150	990	1020	1025	1040	1040	1010	1050	1030	1050	1010	940	930	950	950	940	940	940	940	940
27	1232	1220	1193	1198	1196	1199	1093	1094	1094	1095	1121	1102	1110	1100	1099	1060	1055	1140	1130	1120	1110	1085	1080	1050	1165	1140	1070	1000	1100	1020	1000	1015	1030	1040	1050	1040	950	950	940	925	920	925	925	920	920	920	920	920
28	1257	1244	1207	1186	1178	1180	1184	1094	1089	1091	1096	1101	1100	1100	1098	1085	1130	1130	1120	1110	1090	1085	1065	1020	1160	1150	1060	1000	1030	1020	970	1010	1020	1025	1020	1020	940	940	935	920	900	890	893	900	900	900	900	900
29	1267	1256	1231	1203	1183	1173	1166	1157	1080	1093	1090	1095	1111	1090	1080	1072	1120	1120	1110	1095	1070	1075	1065	1110	1100	1160	1130	1050	980	970	950	940	1010	1015	990	940	940	940	950	910	893	930	893	880	880	860	890	880
30	1261	1245	1231	1195	1183	1184	1175	1138	1150	1072	1082	1087	1099	1085	1080	1075	1105	1105	1100	1080	1065	1050	1055	1045	1100	1155	1160	1100	1010	950	935	970	970	1000	980	940	940	925	915	910	900	890	900	870	870	870	870	870
31	1263	1253	1215	1197	1192	1195	1173	1153	1141	1154	1152	1156	1100	1085	1090	1130	1120	1075	1075	1075	1060	1040	1030	1015	990	1130	1155	1130	1060	960	920	955	945	950	945	940	920	910	910	905	900	880	860	850	850	850	850	850
32	1280	1238	1223	1225	1213	1228	1211	1184	1131	1128	1110	1137	1090	1085	1140	1130	1120	1080	1060	1070	1050	1030	1020	1000	970	1070	1120	1100	1070	950	890	970	955	940	935	935	950	900	910	910	893	875	860	855	855	855	855	855
33	1275	1250	1258	1233	1178	1223	1223	1208	1149	1119	1078	1107	1090	1085	1150	1130	1100	1080	1075	1060	1040	1020	1010	960	955	990	1000	1020	1060	940	895	930	935	935	930	940	950	920	900	910	893	870	860	850	850	850	850	850
34	1282	1237	1223	1188	1157	1174	1167	1154	1150	1113	1082	1085	1165	1148	1150	1130	1090	1085	1060	1055	1030	1010	985	965	945	980	960	1020	1040	930	900	940	940	940	930	955	965	950	940	890	880	865	850	840	840	840	840	840
35	1255	1225	1214	1184	1163	1164	1155	1139	1122	1097	1079	1086	1180	1160	1165	1130	1100	1090	1060	1050	1025	1005	980	960	940	980	1000	1010	1000	930	890	950	950	920	925	955	925	930	930	910	880	850	850	850	850	850	850	850
36	1226	1198	1199	1200	1187	1156	1123	1099	1088	1063	1075	1141	1180	1160	1180	1150	1100	1090	1060	1045	1020	1010	975	955	940	970	975	975	925	890	880	890	930	905	920	910	910	910	900	875	865	865	860	850	860	860	860	860
37	1202	1179	1166	1165	1153	1146	1079	1039	1068	1074	1067	1141	1180	1160	1200	1160	1110	1090	1060	1040	1020	985	970	950	930	935	945	940	930	890	880	890	895	905	890	885	880	880	870	850	845	850	855	855	855	855	855	855
38	1198	1181	1170	1144	1123	1124	1057	1018	1082	1057	1066	1160	1180	1180	1200	1170	1120	1090	1060	1040	1010	975	945	930	930	920	940	930	920	900	880	905	900	900	910	900	890	865	850	850	840	845	840	840	840	840	840	840
39	1251	1271	1283	1224	1107	1097	1034	1025	1067	1054	1067	1175	1180	1175	1180	1170	1100	1090	1060	1040	1010	970	940	970	900	950	945	935	920	910	885	905	930	900	910	910	890	870	860	855	850	845	835	835	835	835	835	835
40	1254	1302	1303	1233	1128	1075	1005	1058	1047	1054	1074	1170	1170	1170	1170	1160	1100	1065	1060	1040	1010	980	1030	980	900	920	900	890	895	910	880	930	930	870	905	910	890	870	855	850	845	845	840	835	835	835	835	835
41	1279	1251	1312	1214	1086	1031	1012	1058	1023	1037	1080	1167	1165	1160	1160	1155	1100	1065	1060	1040	1045	1050	1040	980	885	920	920	910	895	895	880	900	870	840	890	905	880	845	840	840	840	835	830	830	830	830	830	830
42	1335	1310	1225	1150	1076	1002	1038	1031	1014	1041	1097	1162	1150	1155	1145	1140	1090	1060	1045	1030	1010	1010	970	925	875	860	930	925	880	865	850	890	860	860	840	870	860	855	855	845	840	835	830	830	830	830	830	830
43	1386	1301	1249	1114	1065	976	1017	1017	1042	1035	1077	1151	1152	1142	1144	1140	1080	1055	1040	1035	995	960	930	900	860	835	910	950	925	900	840	830	850	845	855	840	850	850	845	840	835	835	835	835	835	835	835	835
44	1375	1274	1183	1109	1028	970	974	1029	1047	1024	1041	1123	1101	1096	1134	1130	1075	1060	1050	1035	990	945	930	900	865	840	890	955	950	955	885	860	860	870	875	910	840	840	840	835	835	840	840	840	840	840	840	840
45	1347	1272	1176	1114	1047	972	975	1007	1041	1014	1021	1065	1057	1069	1092	1120	1070	1060	1060	1035	1020	1010	950	930	880	870	870	910	950	950	900	870	850	840	855	875	840	835	835	835	840	850	850	845	845	845	845	845
46	1345	1305	1181	1119	1061	974	970	974	1033	1012	995	1033	1019	1040	1069	1115	1115	1035	1010	990	955	985	955	935	905	880	895	950	920	950	950	870	835	830	840	875	840	835	830	840	845	855	855	855	855	855	855	855
47	1354	1251	1171	1112	1065	975	964	955	1024	1005	980	968	1013	1067	1048	1082	1110	1020	1015	1000	990	975	955	945	915	905	925	920	890	920	930	865	810	810	850	860	910	835	830	840	850	850	840	830	830	830	830	830
48	1348	1208	1144	1125	1071	999	950	955	979	1006	975	972	987	1003	1044	1080	1105	1035	1020	1005	990	975	955	960	950	940	930	930	920	895	870	860	795	790	830	850	840	835	805	725	845	855	850	800	800	800	800	800
49	1336	1199	1115	1117	1105	996	958	950	971	1010	973	955	966	990	1067	1101	1080	1020	1008	990	960	985	975	970	960	940	925	940	930	915	910	910	900	935	795	805	830	815	770	715	775	840	820	790	790	790	790	790
50	1313	1202	1115	1088	1081	981	973	944	972	982	964	946	960	974	988	1070	1050	1040	1007	976	1000	1015	1010	975	965	940	935	960	935	925	920	915	910	885	850	820	785	795	780	740	770	795	795	780	780	780	780	780
51	1325	1217	1133	1093	1053	993	961	948	947	962	959	935	937	953	977	1050	1040	1035	1011	1007	1015	1005	1000	980	965	950	940	940	940	930	925	920	915	910	880	850	800	790	790	780	815	815	790	860	860	860	860	860
52	1303	1227	1141	1100	1059	996	965	957	957	955	959	930	927	961	977	1038	1035	1030	1020	1015	1020	1005	990	975	965	950	960	960	940	940	930	925	920	915	905	860	825	795	785	780	800	820	820	840	840	840	840	840
53	1302	1196	1141	1097	1093	1012	977	957	955	967	936	926	918	947	987	984	1030	975	1000	1010	1010	1005	995	965	965	950	935	940	940	930	935	930	925	915	905	870	835	810	790	780	770	795	810	820	820	820	820	820
54	1301	1229	1169	1125	1082	1009	977	1002	1177	994	942	927	913	935	971	970	987	950	950	975	985	980	990	995	970	945	935	925	930	940	935	935	925	915	905	870	840	820	800	760	765	780	800	810	810	810	810	810
55	1283	1224	1174	1132	1095	1011	981	950	1011	942	916	910	911	936	960	953	968	996	1014	920	950	960	950	925	935	925	915	910	920	940	935	935	930	920	905	875	840	825	790	770	755	770	790	800	800	800	800	800
56	1294	1220	1166	1164	1119	1027	960	922	901	903	896	906	916	944	952	946	961	982	1018	1022	890	900	890	880	880	865	865	900	910	935	945	935	930	915	905	875	845	805	795	765	750	765	765	795	795	795	795	795
57	1307	1214	1178	1171	1130	1043	949	930	899	897	900	892	904	922	926	935	958	1001	1020	1011	995	1005	995	860	860	860	880	900	911	941	943	923	926	910	895	866	822	800	797	765	748	762	777	786	786	786	786	786
58	1282	1217	1155	1168	1132	1048	930	930	899	881	881	891	906	916	929	943	994	1004	1004	1003	997	1007	992	992	940	850	860	880	900	920	900	900	880	860	867	837	818	803	793	762	746	761	782	788	788	788	788	788
59	1256	1212	1200	1183	1135	1036	921	892	888	865	888	908	940	961	977	996	983	1004	1037	1023	1045	1045	1014	991	995	840	850	860	880	880	880	880	860	850	887	837	801	800	793	761	742	759	779	788	758	788	788	798
60	1267	1202	1189	1156	1120	1052	904	877	852	873	920	934	974	1000	1029	1064	1025	1026	1049	1058	1076	1059	1033	1002	980	967	840	850	860	860	860	860	840	897	883	845	786	798	791	763	746	758	778	789	788	789	788	788

Table 12-8 Bottom Elevation of Model Layer 4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1834	1765	1674	1710	1645	1608	1591	1561	1524	1504	1466	1476	1490	1528	1495	1456	1456	1431	1395	1383	1397	1416	1412	1409	1403	1437	1399	1392	1419	1436	1477	1454	1443	1442	1431	1406	1332	1275	1255	1247	1233	1221	1213	1208	1208	1208	1208	1208
2	1951	1836	1866	1731	1698	1643	1597	1573	1549	1506	1473	1458	1465	1493	1528	1444	1403	1419	1402	1373	1374	1394	1394	1395	1396	1411	1381	1388	1413	1452	1456	1433	1424	1407	1383	1349	1323	1320	1315	1280	1243	1229	1219	1217	1217	1217	1217	1217
3	1679	1825	1768	1699	1657	1606	1576	1549	1523	1505	1473	1455	1443	1483	1460	1397	1372	1376	1397	1372	1352	1365	1368	1375	1365	1384	1360	1386	1403	1414	1417	1409	1394	1372	1352	1328	1313	1307	1288	1268	1255	1245	1235	1226	1226	1226	1225	1226
4	1603	1761	1748	1729	1684	1616	1562	1525	1517	1519	1513	1446	1464	1429	1435	1389	1373	1357	1372	1375	1362	1338	1349	1359	1364	1365	1343	1374	1400	1403	1394	1375	1358	1346	1340	1334	1313	1282	1269	1259	1250	1243	1236	1229	1229	1229	1229	1229
5	1778	1734	1690	1682	1633	1599	1542	1535	1555	1552	1462	1449	1439	1412	1420	1393	1355	1341	1348	1355	1349	1330	1341	1350	1353	1340	1340	1376	1330	1315	1265	1340	1368	1336	1324	1312	1291	1272	1258	1249	1238	1230	1231	1230	1230	1230	1230	1230
6	1850	1766	1822	1659	1575	1611	1615	1639	1525	1478	1429	1439	1434	1418	1419	1380	1354	1332	1327	1335	1327	1308	1324	1325	1320	1329	1344	1315	1315	1250	1275	1367	1350	1329	1309	1297	1266	1269	1258	1250	1240	1235	1220	1200	1200	1200	1200	1200
7	1685	1808	1784	1654	1591	1545	1618	1512	1444	1428	1417	1418	1411	1420	1404	1371	1357	1342	1328	1309	1309	1304	1320	1304	1313	1324	1330	1250	1255	1265	1240	1215	1220	1240	1300	1290	1295	1248	1230	1211	1191	1155	1150	1135	1135	1135	1135	1135
8	1576	1728	1690	1639	1505	1548	1465	1463	1415	1404	1406	1398	1390	1396	1383	1359	1348	1337	1321	1305	1289	1292	1304	1296	1325	1345	1300	1240	1230	1210	1190	1200	1200	1210	1220	1220	1210	1135	1170	1145	1130	1115	1120	1120	1120	1120	1120	1120
9	1551	1578	1558	1438	1474	1423	1418	1435	1401	1424	1395	1383	1399	1371	1362	1347	1332	1322	1310	1303	1295	1270	1275	1271	1291	1295	1240	1200	1190	1185	1190	1185	1175	1165	1160	1145	1130	1105	1090	1085	1070	1080	1090	1100	1100	1100	1100	1100
10	1441	1502	1447	1441	1421	1401	1407	1397	1417	1389	1398	1396	1378	1344	1341	1339	1330	1319	1311	1302	1288	1275	1256	1220	1285	1235	1195	1170	1160	1160	1160	1170	1160	1130	1140	1120	1080	1065	1060	1050	1070	1090	1090	1075	1075	1075	1075	1075
11	1416	1422	1411	1395	1391	1393	1393	1404	1394	1421	1412	1379	1332	1328	1322	1315	1314	1302	1290	1265	1278	1270	1215	1160	1180	1180	1165	1170	1145	1140	1135	1140	1140	1110	1100	1075	1040	1035	1030	1030	1055	1095	1075	1130	1130	1130	1130	1130
12	1382	1386	1382	1402	1394	1402	1471	1378	1405	1365	1341	1336	1312	1310	1306	1301	1294	1285	1279	1274	1272	1268	1145	1115	1130	1155	1160	1155	1125	1125	1105	1110	1090	1055	1040	1025	1000	1005	1015	1030	1080	1085	1090	1100	1100	1100	1100	1100
13	1346	1328	1340	1363	1341	1399	1394	1369	1359	1331	1325	1325	1317	1312	1306	1297	1287	1277	1271	1264	1258	1185	1130	1090	1100	1120	1140	1140	1130	1095	1075	1060	1030	1010	1000	1000	995	1020	1075	1060	1075	1070	1090	1100	1100	1100	1100	1100
14	1321	1323	1361	1339	1328	1369	1363	1319	1324	1327	1324	1319	1309	1305	1297	1292	1285	1275	1270	1264	1220	1160	1155	1135	1100	1100	1095	1110	1105	1075	1050	1025	980	970	970	990	1075	1060	1035	1050	1095	1050	1070	1035	1035	1035	1035	1035
15	1299	1294	1288	1287	1295	1289	1270	1283	1371	1320	1317	1312	1297	1288	1281	1280	1276	1270	1265	1260	1215	1160	1135	1130	1085	1075	1065	1060	1050	1035	1020	980	970	960	1010	1040	1060	1060	1060	1060	1040	1005	1025	960	950	960	960	960
16	1287	1277	1272	1271	1275	1272	1268	1269	1293	1139	1146	1134	1120	1111	1110	1105	1170	1165	1261	1254	1160	1135	1105	1065	1050	1045	1055	1050	1030	980	985	980	960	960	930	1015	1030	1040	1040	1040	1010	990	980	970	970	970	970	970
17	1286	1272	1264	1262	1265	1264	1264	1265	1136	1133	1134	1124	1110	1106	1101	1091	1150	1125	1252	1125	1130	1120	1100	1060	1020	1025	1055	1040	1000	930	980	975	960	940	950	960	990	1000	990	1000	980	975	950	980	980	980	980	980
18	1230	1266	1253	1251	1252	1255	1073	1075	1097	1122	1114	1111	1075	1075	1075	1075	1130	1115	1110	1110	1105	1095	1080	1040	1020	1025	1000	980	985	985	975	965	955	930	930	935	945	950	970	965	980	975	955	955	955	955	955	955
19	1302	1266	1246	1239	1239	1238	1060	1065	1081	1100	1097	1082	1040	1040	1040	1155	1120	1110	1105	1100	1090	1055	1050	1040	1030	1000	1005	1000	990	975	975	965	960	935	935	940	940	940	955	965	970	965	950	940	940	940	940	940
20	1305	1269	1240	1226	1045	1048	1048	1055	1071	1087	1088	1079	1050	1068	1061	1145	1115	1090	1080	1065	1050	1050	1020	990	970	995	1005	1000	990	980	970	965	960	940	935	925	950	940	950	945	955	960	945	925	925	925	925	925
21	1309	1273	1055	1036	1034	1037	1035	1042	1054	1051	1087	1077	1060	1055	1045	1135	1105	1085	1065	1050	1025	1015	990	975	960	965	970	975	980	975	960	955	960	945	940	935	930	925	940	920	890	920	925	960	960	960	960	960
22	1303	1280	1068	1030	1026	1025	1023	1025	1036	1039	1060	1057	1050	1040	1035	1130	1090	1070	1055	1035	1020	1005	990	975	955	950	955	950	970	980	980	955	950	945	935	930	910	930	935	930	910	885	930	945	945	945	945	945
23	1277	1276	1254	1046	1022	1022	1022	1019	1023	1023	1035	1045	1041	1035	1145	1110	1070	1050	1040	1020	1010	990	985	975	965	945	935	945	965	975	985	945	940	930	925	930	910	920	935	950	910	895	910	920	920	920	920	920
24	1269	1244	1253	1233	1023	1019	1018	1019	1017	1019	1020	1033	1036	1019	1115	1090	1045	1040	1045	1015	1005	1000	985	980	970	950	940	950	965	970	980	940	935	920	900	935	905	920	930	945	910	865	900	890	890	890	890	890
25	1281	1238	1222	1223	1207	1005	1005	1004	1005	1010	1017	1024	1024	1006	993	1065	1045	1040	1060	1035	995	1005	995	985	975	970	970	1070	985	990	1005	930	935	930	920	920	920	935	890	915	870	850	870	865	865	865	865	865
26	1245	1235	1199	1213	1213	1006	996	1002	998	1004	1010	1009	1000	1010	995	1035	1025	1080	1070	1065	1035	990	970	990	965	1065	960	1080	1130	965	960	945	955	950	920	960	945	970	990	890	850	860	860	845	845	845	845	845
27	1222	1210	1183	1186	1186	1189	993	994	994	995	1021	1002	1010	1000	999	1025	1005	1100	1085	1075	1045	1010	1000	970	1080	1055	990	960	1080	995	930	945	950	960	960	960	900	930	875	855	830	840	845	840	840	840	840	840
28	1247	1234	1197	1176	1168	1170	1174	994	989	991	996	1001	1000	1000	998	996	1100	1100	1070	1065	1030	1015	993	940	1075	1065	1000	960	1010	995	930	940	950	960	950	935	865	895	865	820	820	820	825	835	835	835	835	835
29	1277	1246	1221	1193	1173	1163	1156	1147	960	993	990	995	1011	990	980	972	1070	1090	1070	1055	1015	1010	995	1030	1020	1075	1050	1010	960	950	925	900	925	935	905	845	860	870	860	815	830	830	820	805	805	805	805	805
30	1251	1235	1221	1185	1173	1174	1166	1128	1140	972	982	997	999	985	980	975	1065	1065	1055	1040	1020	990	985	970	1020	1075	1085	1060	990	930	910	935	895	905	880	845	850	825	815	820	820	805	810	780	780	780	780	780
31	1253	1243	1205	1187	1182	1165	1163	1143	1131	1144	1142	1146	1000	985	980	1115	1065	1010	1015	1030	1020	990	965	945	915	1050	1080	1090	1040	940	895	930	930	910	875	855	820	820	815	805	800	785	760	770	770	770	770	770
32	1270	1228	1213	1215	1203	1218	1201	1174	1121	1118	1100	1127	990	985	1125	1100	1080	1010	990	1010	1010	985	960	935	900	995	1050	1065	1050	930	860	860	890	875	865	855	860	815	810	810	795	780	740	755	755	755	755	755
33	1265	1240	1248	1220	1168	1213	1213	1158	1139	1109	1068	1097	990	985	1130	1095	1045	1005	1000	995	995	980	965	925	865	915	935	985	1035	880	825	860	850	985	850	860	875	840	825	825	790	775	760	750	750	750	750	750
34	1272	1227	1213	1178	1147	1164	1157	1144	1140	1103	1072	1075	1162	1142	1135	1090	1025	1005	980	980	970	965	945	915	880	910	915	985	1015	860	820	860	910	990	850	865	865	830	810	780	780	770	755	745	745	745	745	745
35	1245	1215	1204	1174	1153	1154	1145	1129	1112	1087	1069	1076	1174	1145	1130	1060	1020	1010	980	970	955	945	935	915	885	915	935	975	980	870	920	925	925	980	850	870	815	820	830	810	790	770	755	755	755	755	755	755
36	1216	1188	1189	1190	1177	1145	1113	1089	1078	1073	1065	1131	1173	1150	1130	1070	1020	1005	975	965	940	940	925	910	890	905	920	940	905	850	840	865	870	825	835	830	780	820	815	790	775	785	770	765	765	765	765	765
37	1192	1169	1156	1155	1143	1135	1069	1029	1058	1054	1057	1131	1173	1155	1140	1095	1025	1005	975	955	940	905	900	890	880	875	895	910	910	840	855	840	830	825	815	855	805	795	790	780	760	790	805	825	825	825	825	825
38	1188	1171	1160	1134	1113	1114	1047	1006	1072	1047	1055	1173	1169	1165	1150	1085	1030	1005	975	955	925	890	865	860	880	870	905	910	895	865	860	825	850	840	830	815	810	790	780	770	770	780	780	810	810	810	810	810
39	1241	1261	1273	1214	1097	1087	1024	1015	1057	1044	1057	1165	1169	1165	1130	1090	1020	1005	975	950	920	880	855	890	870	925	920	915	900	880	860	875	905	975	860	800	780	770	770	765	770	780	780	795	795	795	795	795
40	1244	1292	1293	1223	1118	1065	995	1046	1037	1044	1064	1160	1155	1155	1120	1080	1015	980	970	950	915	870	930	895	835	885	875	870	870	870	835	835	855	785	810	810	790	780	770	765	770	785	750	735	735	735	735	735
41	1269	1251	1302	1204	1076	1021	1002	1046	1013	1027	1070	1157	1151	1145	1125	1075	1020	980	975	950	950	950	940	895	815	860	880	870	850	835	805	820	785	740	780	810	780	760	760	770	750	790	750	720	720	720	720	720
42	1325	1300	1215	1140	1066	992	1028	1021	1004	1031	1087	1152	1145	1140	1130	1070	1010	980	960	940	920	915	875	840	805	795	870	860	805	785	765	795	780	750	740	780	775	795	790	775	760	795	755	730	730	730	730	730
43	1376	1291	1239	1104	1055	965	1007	1007	1032	1025	1067	1146	1147	1135	1134	1090	1000	975	955	950	905	870	840	820	790	770	835	870	840	805	745	730	740	735	755	755	795	805	780	750	765	790	800	755	755	755	755	755
44	1365	1264	1173	1099	1018	963	964	1019	1037	1014	1031	1113	1099	1093	1129	1115	1015	980	970	950	935	860	850	825	795	770	810	870	870	855	785	750	745	760	775	830	810	780	770	755	770	815	813	780	780	780	780	780
45	1337	1262	1166	1104	1037	962	965	997	1031	1004	1011	1075	1047	1066	1087	1110	1030	990	980	955	935	925	880	855	810	790	790	825	865	850	800	760	740	730	755	805	810	775	755	770	790	823	823	795	795	795	795	795
46	1335	1295	1171	1109	1051	964	960	964	1023	1002	985	1023	1009	1030	1066	1105	1095	970	935	910	930	900	880	855	825	795	810	910	850	885	980	780	735	720	740	785	800	795	740	600	795	829	829	845	845	845	845	845
47	1344	1241	1161	1102	1055	965	954	945	1014	995	970	978	1003	1054	1045	1072	1095	1000	955	920	935	865	875	860	830	820	845	850	830	870	890	835	750	710	740	780	825	770	810	820	820	823	813	804	804	804	804	804
48	1338	1198	1134	1116	1061	979	940	945	969	936	965	952	977	993	1041	1068	1090	1015	960	930	935	875	875	870	965	860	865	870	865	850	930	830	775	765	755	750	740	755	755	699	820	830	825	785	775	775	775	775
49	1326	1189	1105	1107	1095	986	948	940	961	1000	963	945	955	980	1064	1090	1060	930	968	930	930	895	885	895	885	880	875	900	890	875	975	860	875	815	775	775	770	740	710	689	755	820	800	770	765	765	765	765
50	1303	1192	1105	1078	1071	971	963	934	962	972	954	936	950	964	978	1060	1035	1015	972	926	930	930	930	930	905	895	895	920	895	890	865	885	880	860	830	800	765	775	760	715	745	770	790	770	765	765	765	765
51	1315	1207	1123	1083	1053	973	951	938	937	952	949	925	927	943	967	1041	1030	1015	981	967	955	925	920	910	910	905	930	900	905	895	890	965	885	880	855	830	765	775	775	758	794	798	780	850	850	850	850	850
52	1293	1217	1131	1090	1059	986	955	947	947	945	949	920	917	951	967	1028	1024	1015	995	975	950	930	915	910	910	915	920	920	905	905	895	990	890	885	875	835	805	780	775	763	785	815	810	830	830	830	830	830
53	1292	1186	1131	1087	1073	1002	967	947	945	957	925	916	908	937	977	974	1020	963	985	985	950	945	930	920	905	855	890	900	905	895	900	900	895	885	875	845	815	800	773	768	760	785	830	810	810	810	810	810
54	1291	1219	1159	1115	1072	999	967	932	1167	974	932	917	903	925	961	960	977	939	936	955	945	925	930	935	910	850	885	965	895	905	905	905	900	895	890	860	816	803	790	750	755	770	790	800	800	800	800	800
55	1273	1214	1164	1122	1085	1001	971	950	1001	932	906	930	901	926	950	949	958	976	1004	915	925	910	895	865	875	870	850	970	890	915	920	925	920	903	886	855	823	820	780	760	745	760	780	790	790	790	790	790
56	1284	1210	1156	1154	1109	1017	950	912	891	893	885	896	906	934	942	936	951	972	1008	1012	875	865	840	825	825	810	835	975	894	919	929	919	914	899	889	860	840	795	765	755	740	755	775	785	785	785	785	785
57	1297	1204	1168	1161	1120	1039	939	890	887	887	890	882	894	912	915	925	948	931	1010	1001	995	996	985	830	830	830	850	984	895	925	927	907	912	894	879	861	812	790	787	755	738	752	767	776	776	776	776	776
58	1272	1207	1166	1158	1122	1038	920	890	888	871	871	881	895	906	919	931	964	934	994	993	997	997	982	982	824	834	844	964	884	884	864	864	864	844	857	827	808	793	789	752	736	751	772	778	778	778	778	778
59	1246	1202	1190	1173	1125	1026	911	882	879	855	879	898	930	951	967	986	973	934	1027	1013	1035	1036	1004	981	985	824	834	844	864	864	864	864	844	840	877	827	791	780	783	751	732	749	769	778	778	778	778	778
60	1257	1192	1178	1146	1110	1042	894	857	842	853	910	924	964	990	1019	1054	1015	1018	1039	1048	1066	1049	1023	992	970	957	824	834	844	844	844	845	835	887	873	835	776	788	781	753	736	748	768	778	778	778	778	778

Table 12-9 Bottom Elevation of Model Layer 5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1624	1775	1804	1700	1635	1598	1561	1551	1514	1494	1476	1466	1480	1518	1485	1446	1446	1471	1365	1373	1387	1406	1402	1393	1393	1427	1389	1382	1409	1426	1467	1444	1433	1432	1421	1396	1322	1265	1245	1237	1223	1211	1203	1198	1198	1198	1198	1198
2	1941	1826	1856	1721	1686	1633	1587	1563	1539	1496	1463	1448	1456	1483	1518	1434	1393	1409	1397	1360	1364	1384	1384	1385	1386	1401	1371	1378	1403	1442	1445	1423	1414	1397	1373	1339	1313	1310	1305	1270	1233	1219	1209	1207	1207	1207	1207	1207
3	1659	1615	1758	1689	1647	1596	1566	1536	1513	1495	1463	1445	1433	1473	1450	1387	1362	1366	1387	1362	1342	1355	1358	1365	1375	1374	1350	1376	1393	1404	1407	1339	1364	1362	1342	1318	1303	1297	1278	1258	1245	1235	1225	1216	1216	1216	1216	1216
4	1793	1771	1738	1779	1674	1606	1552	1515	1507	1509	1503	1436	1454	1419	1425	1379	1363	1347	1362	1366	1352	1328	1336	1349	1354	1355	1333	1364	1330	1393	1384	1366	1348	1335	1330	1324	1303	1272	1259	1249	1240	1233	1226	1219	1219	1219	1219	1219
5	1758	1724	1680	1672	1620	1589	1532	1525	1545	1542	1452	1439	1428	1402	1410	1383	1345	1331	1338	1345	1339	1323	1331	1340	1343	1330	1330	1366	1310	1295	1275	1330	1358	1325	1314	1302	1281	1262	1248	1239	1229	1220	1221	1220	1220	1220	1220	1220
6	1840	1756	1812	1649	1566	1501	1605	1628	1515	1468	1419	1429	1424	1408	1409	1370	1344	1372	1317	1325	1317	1298	1314	1315	1310	1316	1334	1305	1305	1230	1265	1357	1340	1319	1299	1267	1276	1259	1248	1240	1230	1225	1213	1190	1190	1190	1190	1190
7	1675	1798	1774	1644	1581	1535	1608	1502	1434	1418	1407	1408	1401	1410	1394	1361	1347	1332	1318	1299	1299	1294	1310	1294	1303	1314	1310	1230	1235	1245	1233	1205	1210	1230	1290	1280	1285	1233	1215	1196	1175	1125	1115	1095	1095	1095	1095	1095
8	1566	1718	1680	1689	1595	1539	1455	1450	1405	1394	1396	1388	1380	1386	1373	1349	1338	1327	1311	1295	1279	1282	1294	1286	1315	1335	1280	1210	1200	1180	1180	1190	1190	1190	1200	1190	1180	1160	1135	1110	1095	1075	1060	1040	1040	1040	1040	1040
9	1541	1568	1548	1488	1464	1413	1408	1425	1391	1414	1385	1373	1389	1361	1352	1337	1327	1312	1300	1293	1285	1260	1265	1261	1281	1285	1220	1170	1155	1150	1150	1145	1145	1125	1115	1095	1080	1055	1040	1040	1025	1035	1045	1010	1010	1010	1010	1010
10	1431	1492	1437	1431	1411	1397	1397	1387	1407	1379	1388	1376	1368	1334	1331	1329	1320	1309	1301	1292	1278	1265	1246	1210	1275	1225	1185	1150	1125	1120	1115	1120	1110	1080	1090	1065	1025	1005	1000	990	1010	1025	1015	995	995	995	995	995
11	1408	1412	1401	1385	1381	1383	1383	1394	1384	1411	1402	1369	1322	1318	1312	1305	1304	1292	1260	1275	1268	1260	1205	1150	1170	1170	1155	1160	1115	1095	1085	1090	1090	1060	1045	1015	980	970	960	950	975	1015	995	1045	1045	1045	1045	1045
12	1372	1376	1372	1392	1384	1392	1461	1368	1395	1355	1337	1326	1302	1300	1296	1291	1284	1275	1269	1264	1262	1258	1135	1105	1120	1145	1150	1145	1105	1075	1055	1060	1035	1000	980	965	935	935	940	950	1000	1005	1020	1010	1010	1010	1010	1010
13	1336	1318	1330	1354	1331	1389	1384	1379	1349	1321	1315	1315	1307	1302	1296	1297	1277	1267	1261	1254	1248	1175	1120	1080	1090	1110	1130	1130	1090	1045	1025	1005	975	950	940	935	925	950	960	985	995	990	1015	1020	1020	1020	1020	1020
14	1311	1313	1351	1329	1318	1359	1353	1309	1314	1317	1314	1309	1299	1295	1287	1282	1275	1265	1260	1254	1210	1150	1145	1125	1090	1090	1085	1080	1055	1020	995	970	920	910	905	920	1005	990	965	980	1025	980	1000	965	965	965	965	965
15	1289	1284	1278	1277	1285	1279	1269	1273	1301	1310	1307	1302	1287	1278	1271	1270	1265	1260	1255	1250	1235	1150	1125	1120	1075	1055	1035	1010	995	990	965	920	910	915	945	970	990	990	1000	990	970	935	955	890	890	890	890	890
16	1277	1267	1262	1261	1265	1262	1258	1259	1283	1129	1136	1124	1110	1101	1100	1095	1160	1155	1251	1244	1150	1125	1085	1035	1020	995	1005	995	975	925	925	920	895	895	920	945	960	970	970	970	940	920	910	900	900	930	900	900
17	1278	1262	1254	1252	1255	1254	1254	1255	1096	1123	1124	1114	1100	1096	1091	1081	1120	1100	1242	1105	1110	1090	1060	1070	970	970	1000	965	945	930	920	915	895	875	880	890	920	930	920	930	910	905	910	910	910	910	910	910
18	1290	1256	1243	1241	1242	1245	1063	1066	1087	1112	1104	1101	1065	1055	1065	1065	1065	1045	1070	1075	1065	1050	1030	985	965	970	945	925	925	925	915	900	890	860	860	865	875	880	900	895	910	905	865	885	885	885	885	865
19	1292	1256	1236	1229	1229	1228	1050	1055	1071	1090	1087	1072	1030	1030	1030	1145	1065	1050	1060	1055	1045	1005	935	985	970	940	945	940	930	915	910	900	895	865	865	870	870	870	985	895	900	895	880	870	870	870	870	870
20	1295	1259	1230	1216	1035	1038	1038	1046	1061	1077	1078	1059	1040	1058	1051	1135	1085	1035	1030	1015	1000	995	960	930	910	930	940	935	925	915	905	900	890	870	865	855	880	870	980	875	865	890	975	855	855	855	855	855
21	1299	1263	1045	1026	1024	1027	1025	1032	1044	1041	1077	1067	1050	1045	1035	1125	1085	1030	1005	990	965	950	925	910	895	900	905	910	915	910	895	885	890	875	870	865	860	855	870	850	820	850	855	890	890	890	890	890
22	1293	1270	1058	1020	1016	1015	1013	1015	1025	1029	1050	1047	1040	1030	1025	1120	1070	1015	995	975	955	935	920	905	885	880	890	985	905	910	910	885	860	875	865	860	840	860	865	860	840	815	860	875	875	875	875	875
23	1267	1266	1244	1036	1012	1012	1012	1009	1013	1013	1025	1035	1031	1025	1135	1100	1050	995	960	955	940	915	915	905	895	875	865	875	895	905	915	875	870	860	850	825	835	845	860	875	835	825	840	850	850	850	850	850
24	1259	1234	1243	1223	1013	1009	1008	1009	1007	1009	1010	1023	1026	1009	1105	1080	1015	980	960	950	930	925	910	910	900	880	870	880	895	900	910	870	860	845	820	825	825	840	850	865	930	795	820	810	810	810	810	810
25	1271	1228	1212	1213	1197	995	995	994	995	1000	1007	1014	1014	998	983	1055	995	980	995	970	920	925	920	915	905	900	900	1000	915	910	935	860	860	855	840	840	840	850	805	830	785	750	780	775	775	775	775	775
26	1235	1226	1189	1203	1203	995	988	992	988	994	1020	999	990	1000	985	1025	975	1020	1005	995	960	910	890	915	910	995	865	1005	1055	890	830	875	865	880	845	865	865	865	900	800	760	770	765	750	750	750	750	750
27	1212	1200	1173	1178	1176	1179	983	994	984	985	1011	992	1000	990	989	1015	950	1040	1020	1005	970	930	920	890	1000	975	910	880	1000	915	850	870	865	890	890	865	820	850	790	765	740	745	745	740	740	740	740	740
28	1237	1224	1187	1166	1158	1160	1164	984	979	991	986	991	990	990	988	976	1040	1035	1000	935	960	935	910	860	935	985	920	880	930	915	850	860	875	885	880	865	790	820	785	735	730	720	720	730	730	730	730	730
29	1267	1236	1211	1163	1153	1153	1146	1137	970	983	980	965	1001	980	970	962	1010	1025	1000	985	940	930	915	950	935	990	965	925	875	865	840	820	945	855	830	770	780	790	770	720	730	725	715	700	700	700	700	700
30	1241	1225	1211	1175	1153	1164	1156	1118	1130	962	972	977	989	975	970	965	1000	1000	985	970	945	910	905	865	935	990	1000	975	905	845	825	855	815	820	795	765	770	740	730	730	720	705	710	680	680	680	680	680
31	1243	1233	1195	1177	1172	1175	1153	1133	1121	1134	1132	1136	990	975	970	1060	1015	940	945	955	940	910	890	960	830	955	905	1000	950	850	810	865	870	820	790	775	735	735	725	715	700	685	665	690	690	690	690	690
32	1260	1218	1203	1205	1193	1208	1191	1164	1111	1108	1090	1117	980	975	1105	1040	1010	935	915	930	930	900	875	850	815	935	960	975	950	840	775	800	820	790	790	770	770	725	720	715	695	680	640	655	655	655	655	655
33	1255	1230	1239	1210	1158	1203	1203	1188	1129	1099	1058	1087	980	975	1070	1025	970	925	920	915	910	895	880	840	795	825	945	895	945	790	735	775	760	795	760	770	785	745	725	725	710	675	655	645	645	645	645	645
34	1262	1217	1203	1168	1137	1154	1147	1134	1130	1093	1062	1065	1149	1117	1065	1015	945	925	900	895	865	880	855	825	790	820	825	895	925	770	730	770	820	790	750	765	765	730	705	680	700	670	645	635	635	635	635	635
35	1235	1205	1194	1164	1143	1144	1135	1119	1102	1077	1059	1066	1155	1075	1060	980	940	930	900	885	870	860	845	825	795	825	845	885	895	765	735	835	825	780	750	765	710	715	725	705	685	665	645	645	645	645	645	645
36	1206	1176	1179	1160	1167	1136	1103	1079	1068	1063	1055	1121	1150	1080	1060	990	940	925	890	880	855	855	840	825	805	820	835	855	825	770	760	780	775	730	745	730	675	715	710	680	665	675	660	650	650	650	650	650
37	1182	1159	1146	1145	1133	1126	1059	1019	1046	1054	1047	1121	1140	1095	1070	1015	945	925	890	870	855	820	875	805	795	790	810	830	835	770	785	770	760	755	730	755	730	690	680	670	670	680	690	710	710	710	710	710
38	1178	1161	1150	1124	1103	1104	1037	998	1062	1037	1046	1150	1130	1105	1080	1005	950	925	890	870	840	805	790	775	795	785	825	830	825	795	790	755	780	750	735	715	705	685	670	660	660	665	665	695	695	695	695	695
39	1231	1251	1263	1204	1087	1077	1014	1005	1047	1034	1047	1135	1130	1105	1060	1010	940	925	895	870	840	800	775	810	790	845	840	835	875	805	785	795	790	760	760	695	675	665	660	655	655	665	665	680	680	680	680	680
40	1234	1282	1283	1213	1108	1055	985	1038	1027	1034	1054	1130	1115	1110	1055	1005	935	900	890	870	835	790	850	815	755	805	795	790	790	790	755	740	740	675	710	710	630	675	665	655	655	670	635	620	620	620	620	620
41	1259	1241	1292	1194	1066	1011	992	1038	1003	1017	1060	1127	1110	1100	1060	1005	945	905	900	870	870	870	860	815	735	785	805	795	775	755	725	735	695	650	690	720	685	660	655	660	635	675	635	605	605	605	605	605
42	1315	1250	1205	1130	1056	982	1018	1011	994	1021	1077	1122	1105	1095	1070	1005	945	915	890	870	850	845	805	770	730	725	800	790	735	715	695	720	700	670	655	695	685	700	630	670	650	680	640	615	615	615	615	615
43	1366	1281	1229	1094	1045	956	997	997	1022	1015	1057	1131	1132	1112	1079	1030	940	910	890	885	840	805	775	755	725	705	770	800	770	735	675	660	670	660	675	675	710	715	680	645	655	675	685	640	640	640	640	640
44	1355	1254	1163	1089	1008	950	954	1009	1027	1004	1021	1103	1086	1083	1074	1060	960	920	910	890	845	800	790	765	735	705	745	805	805	790	720	685	675	690	735	755	725	690	670	650	660	705	730	670	670	670	670	670
45	1327	1252	1156	1094	1027	952	955	987	1021	994	1001	1065	1037	1056	1057	1060	980	935	925	900	860	870	825	800	750	730	730	765	805	795	735	695	675	665	695	735	730	665	655	665	685	740	740	695	685	665	685	685
46	1325	1285	1161	1099	1041	954	950	954	1013	992	975	1013	999	1020	1056	1050	1050	925	890	865	850	850	830	805	775	745	755	755	795	825	820	720	670	655	675	715	720	705	640	695	690	750	750	740	740	740	740	740
47	1334	1231	1151	1092	1045	955	944	935	1004	965	960	968	993	1054	1035	1022	1040	950	910	890	865	845	830	815	785	775	800	805	780	815	835	780	700	650	675	710	745	680	710	715	710	740	730	725	725	725	725	725
48	1328	1188	1124	1106	1051	969	930	935	959	986	955	952	967	983	1031	1030	1035	950	930	880	865	835	835	830	825	820	825	830	820	805	780	780	720	705	690	680	660	660	655	620	710	710	715	695	700	700	700	700
49	1316	1179	1095	1097	1085	976	938	930	951	990	953	935	946	970	1054	1056	1010	930	909	875	845	850	845	845	845	840	835	860	850	835	830	835	825	760	710	700	685	640	605	610	645	730	690	670	690	690	690	690
50	1293	1182	1095	1069	1061	961	953	974	952	962	944	926	940	954	968	1020	985	950	912	866	875	875	885	855	865	855	855	880	855	850	840	840	830	800	750	715	665	670	660	640	670	695	700	710	720	720	720	720
51	1305	1197	1113	1073	1043	963	941	978	927	942	939	915	917	933	957	1015	985	950	921	902	895	970	870	860	865	865	860	860	865	855	845	835	835	820	775	735	685	675	685	690	730	745	750	840	840	840	840	840
52	1263	1207	1127	1080	1049	976	945	937	937	935	939	910	907	941	957	1018	990	955	935	910	895	870	860	855	860	870	875	875	850	860	845	835	830	820	785	735	700	660	685	710	740	800	800	820	820	820	820	820
53	1282	1176	1121	1077	1063	992	957	937	935	947	916	906	898	927	967	964	990	925	930	925	895	880	870	860	850	840	840	850	855	840	845	840	830	815	785	745	715	705	720	730	750	775	790	800	800	800	800	800
54	1281	1209	1149	1105	1062	989	957	982	1157	964	922	907	893	915	951	950	967	935	895	695	880	860	865	875	850	830	830	830	840	845	845	845	835	825	800	760	745	750	760	740	745	750	760	790	790	790	790	790
55	1263	1204	1154	1112	1075	991	961	940	991	922	898	890	891	916	940	939	949	956	994	655	865	845	830	800	815	810	800	810	830	850	855	860	855	850	830	795	770	805	770	750	735	750	770	780	760	780	780	760
56	1274	1200	1145	1144	1099	1007	940	902	881	883	876	886	896	924	932	926	941	952	999	1002	815	805	775	760	760	745	770	810	845	870	880	870	850	850	840	815	825	765	775	745	730	745	765	775	775	775	775	775
57	1287	1194	1158	1151	1110	1023	929	880	879	877	880	872	884	902	906	915	938	991	1000	941	975	986	975	765	765	765	765	835	846	876	878	858	863	845	830	846	802	790	777	745	729	742	757	766	766	766	766	766
58	1262	1197	1176	1148	1112	1026	910	890	878	861	861	871	886	895	909	923	974	994	984	983	977	987	972	972	775	785	795	815	835	835	835	835	875	795	842	817	799	780	779	742	726	741	762	768	768	768	768	768
59	1236	1192	1180	1163	1115	1016	901	872	868	845	868	888	920	941	957	976	963	984	1017	1003	1025	1026	994	971	975	775	765	795	815	815	815	815	795	810	867	817	781	780	773	741	722	739	759	758	768	758	768	768
60	1247	1182	1169	1136	1100	1032	884	857	832	853	900	914	954	960	1009	1044	1005	1008	1029	1038	1056	1039	1013	982	960	947	775	785	795	795	795	800	820	877	863	825	765	778	771	743	725	738	759	758	768	768	768	758

Table 12-10 Bottom Elevation of Model Layer 6

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1	1814	1765	1794	1690	1625	1588	1571	1541	1504	1484	1466	1456	1470	1508	1475	1436	1436	1411	1375	1363	1377	1396	1392	1389	1383	1417	1379	1372	1399	1416	1457	1434	1423	1422	1411	1386	1312	1255	1235	1227	1213	1201	1193	1188	1186	1188	1188	1186
2	1931	1816	1646	1711	1678	1623	1577	1553	1529	1486	1453	1438	1446	1473	1508	1424	1383	1399	1382	1350	1354	1374	1374	1375	1376	1391	1361	1368	1393	1432	1436	1413	1404	1387	1363	1329	1303	1300	1295	1260	1223	1209	1199	1197	1197	1197	1197	1197
3	1659	1805	1748	1679	1637	1586	1556	1528	1503	1485	1453	1435	1423	1463	1440	1377	1352	1356	1377	1352	1332	1345	1349	1355	1365	1364	1340	1366	1383	1394	1397	1389	1374	1352	1332	1308	1293	1287	1268	1249	1235	1225	1215	1206	1206	1206	1206	1206
4	1783	1761	1728	1709	1664	1596	1542	1505	1497	1499	1493	1426	1444	1409	1415	1369	1353	1337	1352	1356	1342	1318	1329	1339	1344	1345	1323	1354	1380	1383	1374	1356	1338	1326	1320	1314	1293	1262	1249	1239	1230	1223	1216	1209	1209	1209	1209	1209
5	1758	1714	1670	1662	1610	1579	1522	1515	1535	1532	1442	1429	1418	1392	1400	1373	1335	1321	1328	1335	1320	1310	1321	1330	1333	1320	1320	1356	1300	1285	1265	1320	1348	1316	1304	1292	1271	1252	1238	1229	1218	1210	1211	1210	1210	1210	1210	1210
6	1830	1746	1802	1639	1556	1591	1535	1519	1505	1458	1409	1419	1414	1398	1399	1360	1334	1312	1307	1315	1307	1298	1304	1305	1300	1308	1324	1295	1295	1220	1255	1347	1330	1309	1289	1277	1266	1249	1238	1230	1220	1215	1200	1180	1180	1180	1180	1180
7	1665	1768	1764	1634	1571	1525	1538	1492	1424	1408	1397	1398	1391	1400	1364	1351	1337	1322	1308	1289	1289	1284	1300	1284	1293	1304	1300	1220	1225	1235	1220	1195	1200	1220	1280	1270	1275	1223	1205	1186	1166	1115	1105	1085	1065	1085	1085	1085
8	1556	1708	1670	1679	1585	1528	1445	1440	1395	1384	1386	1378	1370	1376	1363	1339	1328	1317	1301	1265	1269	1272	1264	1276	1305	1325	1270	1200	1190	1170	1170	1160	1180	1160	1190	1180	1170	1150	1125	1100	1085	1065	1040	1020	1020	1020	1020	1020
9	1531	1558	1538	1478	1454	1403	1398	1415	1381	1404	1375	1363	1379	1351	1342	1327	1312	1302	1290	1263	1275	1250	1255	1251	1271	1275	1210	1160	1145	1140	1140	1135	1135	1115	1105	1090	1075	1050	1030	1030	1010	1020	1030	1000	1000	1000	1000	1000
10	1421	1482	1427	1421	1401	1381	1387	1377	1397	1369	1378	1366	1358	1324	1321	1319	1310	1299	1291	1282	1269	1255	1236	1200	1265	1215	1175	1140	1115	1110	1105	1110	1105	1070	1080	1050	1005	985	980	970	995	1010	1000	980	980	980	980	980
11	1398	1402	1391	1375	1371	1373	1373	1384	1374	1401	1392	1359	1312	1308	1302	1295	1294	1262	1270	1265	1258	1250	1195	1140	1160	1160	1145	1150	1105	1085	1075	1075	1070	1040	1025	995	960	950	940	945	960	935	975	1025	1025	1025	1025	1025
12	1362	1366	1362	1382	1374	1382	1451	1359	1385	1345	1321	1316	1292	1290	1286	1281	1274	1265	1259	1254	1252	1248	1125	1095	1110	1135	1140	1135	1095	1060	1035	1040	1015	980	960	945	915	915	920	935	975	975	995	995	995	995	995	995
13	1326	1308	1320	1343	1321	1379	1374	1369	1339	1311	1305	1305	1297	1292	1286	1277	1267	1257	1251	1244	1238	1165	1110	1070	1080	1100	1120	1120	1080	1030	1005	985	955	930	920	915	905	930	960	970	970	950	965	995	995	995	995	995
14	1301	1303	1341	1319	1308	1349	1343	1299	1334	1307	1304	1299	1289	1285	1277	1272	1265	1255	1250	1244	1200	1140	1135	1115	1080	1080	1075	1065	1040	1000	975	950	900	890	985	930	985	970	940	950	995	945	975	945	945	945	945	945
15	1279	1274	1268	1267	1275	1259	1259	1263	1291	1300	1297	1292	1277	1268	1261	1260	1256	1250	1245	1240	1195	1140	1115	1110	1065	1050	1020	995	975	960	945	900	890	895	925	950	970	965	970	965	950	915	935	870	870	870	870	870
16	1267	1257	1252	1251	1255	1252	1248	1249	1273	1119	1126	1114	1100	1091	1090	1085	1150	1145	1241	1234	1140	1115	1080	1020	1005	975	985	975	955	905	905	900	875	875	900	925	940	950	950	950	920	900	890	880	880	880	880	880
17	1268	1252	1244	1242	1245	1244	1244	1245	1086	1113	1114	1104	1090	1086	1081	1071	1110	1093	1232	1095	1100	1075	1040	990	950	950	980	965	925	910	900	895	875	855	860	870	900	910	900	910	890	885	890	890	890	890	890	890
18	1270	1245	1233	1231	1232	1235	1053	1056	1077	1102	1094	1091	1055	1055	1055	1055	1055	1035	1065	1060	1045	1030	1010	965	945	950	925	905	905	905	895	880	870	840	840	845	855	860	880	875	890	885	865	865	865	865	865	865
19	1282	1245	1226	1219	1219	1218	1040	1045	1061	1080	1077	1062	1020	1020	1020	1135	1060	1035	1035	1030	1025	985	975	965	950	920	925	920	910	895	890	880	875	845	845	850	850	850	865	875	880	875	860	850	850	850	850	850
20	1285	1249	1220	1206	1025	1028	1028	1035	1051	1067	1068	1059	1030	1048	1041	1125	1070	1015	1005	990	980	975	940	910	890	910	920	915	905	895	885	880	870	850	845	835	860	850	860	855	865	870	855	835	835	835	835	835
21	1289	1253	1035	1016	1014	1017	1015	1022	1034	1031	1067	1057	1040	1035	1020	1105	1065	1010	995	970	945	930	905	890	875	880	885	890	895	890	875	865	870	855	850	845	840	835	850	830	800	830	835	870	870	870	870	870
22	1283	1260	1048	1010	1006	1005	1003	1005	1016	1019	1040	1037	1030	1015	1005	1100	1050	995	975	955	935	915	900	885	865	860	870	865	865	890	890	865	860	855	845	840	820	840	845	840	820	795	840	855	855	855	855	855
23	1257	1256	1234	1026	1002	1002	1002	999	1003	1003	1015	1025	1011	1000	1110	1080	1030	975	950	935	920	895	895	885	875	855	845	855	875	885	895	855	850	840	830	805	815	825	840	855	815	805	820	830	830	830	830	830
24	1240	1224	1233	1213	1003	999	998	999	997	999	1000	1013	1001	969	1075	1070	995	960	950	930	910	905	830	890	880	860	850	860	875	880	890	850	840	825	800	805	805	820	830	845	810	765	800	790	790	790	790	790
25	1251	1218	1202	1203	1187	965	985	984	985	990	997	1004	994	958	953	1045	975	960	975	950	900	905	900	895	865	880	890	980	895	890	915	840	840	835	820	820	820	830	765	810	765	740	760	755	755	755	755	755
26	1225	1215	1179	1193	1193	985	978	982	978	984	1010	989	980	960	955	1005	955	1000	995	975	940	890	870	895	890	975	865	985	1030	850	875	855	865	860	825	865	845	865	880	780	740	750	745	730	730	730	730	730
27	1202	1193	1163	1168	1166	1169	973	974	974	975	1001	982	990	975	969	995	930	1020	1000	985	950	910	900	870	980	955	890	855	970	865	835	850	865	870	870	860	795	830	770	745	720	725	725	720	720	720	720	720
28	1227	1214	1177	1156	1148	1150	1154	974	969	971	976	981	980	975	968	956	1020	1015	950	975	940	915	890	840	975	965	900	860	910	895	830	840	850	860	855	840	765	800	765	715	710	700	700	710	710	710	710	710
29	1257	1225	1201	1173	1153	1143	1136	1127	960	973	970	975	991	965	950	942	990	1005	980	965	920	915	895	930	915	970	945	905	855	845	820	795	820	830	805	745	755	770	750	700	710	705	695	680	680	690	680	680
30	1231	1215	1201	1165	1153	1154	1146	1108	1120	952	962	967	979	955	950	945	980	990	965	950	925	890	885	865	915	970	990	955	885	825	805	830	790	795	770	740	745	715	710	715	700	685	690	660	660	660	660	660
31	1233	1223	1165	1167	1162	1165	1143	1123	1111	1124	1122	1126	975	955	950	1040	995	920	925	935	920	890	860	840	810	945	975	960	930	830	790	845	850	800	765	750	710	710	700	690	670	660	640	665	665	665	665	665
32	1250	1208	1193	1195	1183	1198	1181	1154	1101	1098	1080	1107	960	955	1085	1020	990	915	895	910	910	880	855	830	795	885	940	955	940	820	755	780	800	770	760	745	745	730	695	680	660	650	615	630	630	630	630	630
33	1245	1220	1228	1200	1148	1193	1193	1178	1119	1089	1048	1077	955	950	1050	1005	950	905	900	895	890	875	860	820	775	805	825	875	925	770	715	755	760	775	740	750	760	720	700	690	670	640	630	620	620	620	620	620
34	1252	1207	1193	1158	1127	1144	1137	1124	1120	1093	1052	1055	1124	1092	1045	995	925	905	880	875	865	860	835	805	770	800	805	875	905	750	710	750	800	770	730	745	745	705	680	650	665	640	620	610	610	610	610	610
35	1225	1195	1184	1154	1133	1134	1125	1109	1092	1067	1049	1056	1105	1050	1040	960	920	910	880	865	850	840	825	805	775	805	825	865	875	765	715	815	805	760	730	745	690	695	700	690	660	640	620	620	620	620	620	620
36	1196	1168	1169	1170	1157	1126	1093	1069	1059	1058	1045	1111	1120	1060	1040	970	920	905	870	860	835	835	820	805	785	800	815	835	805	750	735	755	755	710	725	710	655	695	690	655	640	650	635	625	625	625	625	625
37	1172	1149	1135	1135	1123	1116	1049	1003	1038	1044	1037	1111	1130	1075	1050	995	925	935	870	850	835	800	795	785	775	770	790	810	815	745	760	740	735	730	710	735	680	670	660	650	645	655	665	685	665	685	685	685
38	1168	1151	1143	1114	1093	1094	1027	998	1052	1027	1036	1140	1120	1065	1060	985	930	935	870	850	820	785	760	755	775	765	805	810	805	770	765	705	750	725	715	695	685	665	650	640	640	640	640	670	670	670	670	670
39	1221	1241	1253	1194	1077	1067	1004	995	1037	1024	1037	1125	1115	1065	1040	990	920	905	875	850	820	780	755	790	770	825	820	815	805	760	760	750	775	750	745	675	655	645	640	635	635	645	645	660	660	660	660	660
40	1224	1272	1273	1203	1098	1045	975	1028	1017	1024	1044	1120	1100	1090	1035	985	915	880	870	850	815	770	830	795	735	785	775	770	770	770	735	725	735	570	705	695	670	655	645	635	635	650	615	600	600	600	600	600
41	1249	1231	1282	1164	1056	1001	982	1028	993	1007	1050	1117	1095	1080	1040	985	925	885	860	850	850	850	840	795	715	765	785	775	755	730	705	725	690	645	685	710	665	640	635	640	615	655	615	585	565	585	585	585
42	1305	1280	1195	1120	1046	972	1008	1001	984	1011	1067	1112	1090	1080	1055	990	925	895	870	850	830	825	785	750	710	705	780	770	710	690	675	715	695	665	645	675	665	680	670	650	630	660	620	595	595	595	595	595
43	1356	1271	1219	1064	1035	946	987	987	1012	1005	1047	1121	1122	1102	1064	1015	925	890	870	865	820	785	755	735	705	685	750	775	745	710	655	645	655	645	655	655	690	695	660	625	635	655	665	620	620	620	620	620
44	1345	1244	1153	1079	998	940	944	939	1017	994	1011	1093	1083	1078	1064	1050	950	905	895	870	825	780	770	745	715	685	720	780	775	760	595	665	655	670	685	735	705	670	650	630	640	685	710	650	650	650	650	650
45	1317	1242	1146	1084	1017	942	945	977	1011	984	991	1055	1027	1051	1057	1045	970	920	910	880	860	850	805	780	730	710	705	740	775	765	710	675	655	645	655	715	710	665	635	645	665	720	720	665	665	665	665	665
46	1315	1275	1157	1089	1031	944	940	944	1003	992	965	1003	989	1010	1041	1035	1035	910	870	845	830	830	810	765	755	725	730	730	770	800	795	700	650	635	655	695	700	665	620	675	670	730	730	720	720	720	720	720
47	1324	1221	1147	1082	1035	945	934	925	994	975	950	958	983	1049	1020	1002	1015	925	890	860	845	825	810	795	765	755	780	785	760	795	815	760	680	630	655	690	725	660	690	695	690	720	710	705	705	705	705	705
48	1318	1178	1114	1096	1041	959	920	925	949	976	945	942	957	973	1016	1010	1010	935	910	860	845	815	815	810	805	800	805	810	800	785	760	760	705	690	675	665	645	640	635	600	690	690	700	670	685	685	685	665
49	1306	1169	1065	1067	1075	966	928	920	941	980	943	925	936	960	1044	1041	995	910	888	655	825	830	825	825	825	820	815	840	830	815	810	820	810	745	695	685	670	625	590	595	630	685	680	655	685	685	685	685
50	1293	1172	1085	1058	1051	951	943	914	942	952	934	916	930	944	958	1010	970	945	897	851	860	860	865	835	845	835	835	860	840	835	825	825	815	765	745	700	655	660	650	630	660	685	690	700	710	710	710	710
51	1295	1187	1103	1063	1033	953	931	918	917	932	929	905	907	923	947	1010	975	950	911	852	885	860	855	845	850	850	845	845	850	840	830	820	825	810	765	725	675	670	675	690	720	735	740	830	830	830	830	830
52	1273	1197	1117	1070	1039	966	935	927	927	925	929	900	897	931	947	1008	985	960	930	905	890	860	850	845	850	850	860	860	850	850	835	825	820	810	775	725	695	670	675	730	730	790	790	810	810	810	810	810
53	1272	1166	1117	1067	1053	982	947	927	925	937	906	896	889	917	957	954	985	920	925	920	890	875	865	850	840	830	830	840	845	830	835	830	820	810	780	740	710	695	710	720	740	755	780	790	790	790	790	790
54	1271	1199	1139	1095	1052	979	947	972	1147	954	912	897	883	905	941	940	957	930	893	890	875	855	850	870	845	825	825	825	835	840	840	840	830	820	795	755	735	740	750	730	735	750	770	780	780	780	780	780
55	1253	1194	1144	1102	1065	981	951	930	981	912	886	880	881	906	930	929	939	956	984	850	860	840	825	795	810	805	795	905	825	845	850	855	850	845	825	765	760	795	760	740	725	740	760	770	770	770	770	770
56	1264	1130	1136	1134	1089	937	930	892	871	873	866	876	886	914	922	916	931	952	988	932	810	800	770	755	755	740	765	905	840	865	875	865	860	845	830	805	815	775	765	735	720	735	755	765	765	765	765	765
57	1277	1184	1148	1141	1130	1013	919	870	869	867	870	862	874	892	896	905	928	971	990	981	965	975	955	760	760	760	760	830	841	871	873	853	858	835	820	836	732	770	767	735	718	732	747	756	756	756	756	756
58	1252	1187	1166	1138	1102	1016	900	870	869	851	851	861	876	886	899	913	964	974	974	973	967	977	952	962	770	780	790	810	830	830	830	830	805	765	832	807	788	773	769	732	715	731	752	758	758	758	758	758
59	1226	1182	1170	1153	1135	1006	891	852	858	835	858	878	910	931	947	966	953	974	1307	993	1015	1016	984	961	965	770	760	790	810	810	810	805	785	800	857	807	771	770	763	731	712	729	749	758	758	758	758	758
60	1237	1172	1158	1126	1090	1022	874	847	822	843	890	904	944	970	939	1034	995	998	1019	1028	1046	1029	1003	972	950	937	770	780	730	790	785	790	810	867	853	815	756	768	761	733	716	728	748	758	758	758	758	758

Table 12-11 Data Source and Estimation Method of Present Groundwater Use

Use	Source	Number	Estimation Method
Domestic	Hydrocesus	1208 farms	Number of People × Unit Consumption
			Area × Unit Population × Unit Consumption
	DWA Database	43 farms	Area × Unit Population × Unit Consumption
	NamWater	8 schemes	Monthly Abstraction
Stock Watering	Hydrocensus	1208 farms	Number of Stock × Unit Consumption
			Area / Carrying Capacity × Unit Consumption
	DWA Database	43 farms	Area / Carrying Capacity × Unit Consumption
Irrigation	Hydrocesus	61 farms	Irrigated Area × Unit Consumption
	Permit Holders	41 farms	Monthly Abstraction

Table 12-12 Results of the Hydorcensus

Number of farms In the study area	1,251	
Surveyed farms	1,208	
Number of boreholes	5,726	
Number of boreholes in use	4,467	
People on farms	9,403	on 1006 farms
Number of stock		on 1058 farms
Large stock	103,211	
Small stock	1,268,154	
Ratio of SS and LS	12.29SS/LS	
Irrigated area	566.5ha	on 102 farms
Present groundwater use		on 879 farms
Domestic	3,045m^3/day	
Stock watering	9,919m^3/day	
Irrigation	15,096m^3/day	
Total	28,060m^3/day	
Unit population	1.93capita/1000ha	Average of 831 farms
Unit consumption		
Domestic	408 Litter/day/capita	Average of 623 farms
Large stock	37 Litter/day/head	Average of 828 farms
Small stock	7 Litter/day/head	Average of 146 farms
Irrigation	27.3m^3/day/ha	Average of 84 farms
Carrying capacity		
Large stock	16ha/head	Average of 668 farms
Small stock	3ha/head	Average of 899 farms

Table 12-13 Productions of NamWater Scheme

Unit: m^3/year

Year	Aranos	Leonardville	Stampriet	Gochas	Koes	Kries	Aminius	Onderombapa	Total
1986	207595	80694	24827	61709	61406	12297	22652	11254	482434
1987	225373	84926	51959	67458	44592	17887	18513	13202	523910
1988	229445	87990	67216	64131	52437	18400	19248	14823	553690
1989	214061	78646	64532	73652	60886	19219	18771	20666	550433
1990	231499	69701	55087	73004	72619	18769	18706	24018	563403
1991	236790	64453	47509	76924	81159	15914	22593	25438	570780
1992	260828	72529	41392	74089	78686	13210	19317	30185	590236
1993	243750	63862	38674	63065	83641	9952	15755	28608	547307
1994	254894	60571	48707	63944	80505	10729	17990	29316	566656
1995	264970	64721	50059	62323	73234	10347	27178	28513	581345
1996	227863	62789	56417	60807	70285	10601	25324	24056	538142
1997	220427	61257	59878	58163	66449	10377	25355	15341	517247
1998	242633	71640	68915	62978	75638	11403	37308	20992	591507
1999	236212	70295	76305	60264	79451	11309	43866	26768	604470

Table 12-14 Estimated Irrigation Uses of Permit Holders

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1994	241315	222371	213846	174800	175911	163299	199301	238937	334090	362365	418580	421244	3166060
1995	340450	269628	223514	209903	184949	182637	214159	278014	329975	424403	500396	485130	3643159
1996	414956	454732	425074	347015	338009	324907	254633	368545	371801	405419	471203	447132	4623428
1997	333611	318775	325190	275168	224816	262489	228166	342431	349942	406533	408957	410482	3886560
1998	424061	398935	432321	430346	308883	318409	323477	430729	479120	522470	613145	643734	5320701
1999	492834	502211	391590	604674	370264	296724	309408	357167	379680	478150	554038	584171	5320909

*) Allocated amount: 8,350,000 m3/year

Table 12-15 Estimation of Unit Consumption from Irrigation Permits

Data		Farms	Irrigated Area (ha)	Irrigation Use(m^3/a)	Unit Consumption (m^3/d/ha)	Ratio (%)	Remarks
Allocated amount		30	383.5	5979000	42.0	100	
Monthly Reports	1998			4003193	28.6	68	
	1999			3640425	26.0	62	
Hydrocensus				4139438	29.6	70	
Allocated amount		25	317.5	4352000	37.6	100	Excluding low unit consumption farms
Monthly Reports	1998			3939017	34.0	90	
	1999			3589689	31.0	82	
Hydrocensus				3630628	31.3	83	

Table 12-16 Used Assumptions for Groundwater Use Estimation

Items	Unit	Data Source
Unit Population	1.93 capita/ha	Hydorcensus
Unit Consumption		
Domestic		
Commercial Farms	400 Litter/day/capita	Hydrocensus
Communal Land	30 Litter/day/capita	Chap.10
Stock Watering		
SS	8 Litter/day/head	Hydrocensus
LS	37 Litter/day/head	Hydorcensus
Irrigation	28m3/day/ha	Permit Holders
Carrying Capacity		
SS	3ha/head	Hydorocensus
LS	16ha/head	Hydorcensus
Ratio of SS / LS	12.29	Hydorcensus

Table 12-17 Present Groundwater Use

Domestic Use	Population	Unit Consumption (Litter/day/capita)	Groundwater Use (m^3/day)	Groundwater Use (thousand m^3/a)
Commercial Farms	14,089	400	4,368	1,594
Communal Land	11,588*)	30	348	127
Village Centres (NamWater Scheme)	—	—	1,739	635
Subtotal	—	—	6,455	2,356
Stock Watering Use	Head	Unit Consumption (Litter/day/head)	Groundwater Use (m^3/day)	Groundwater Use (thousand m^3/a)
SS	1,415,675	8	11,326	4,134
LS	115,221	37	4,263	1,556
Subtotal	—	—	15,589	5,690
Irrigation Use	Area (ha)	Unit Consumption (m^3/day/ha)	Groundwater Use (m^3/day)	Groundwater Use (thousand m^3/a)
Permit Holders	—	—	14,578	5,321
Others	153.2	28	4,290	1,566
Subtotal	—	—	18,868	6,887
Total			Groundwater Use (m^3/day)	Groundwater Use (thousand m^3/a)
			40,912	14,933

*) See Table 12-20

Table 12-18 Procedure of Groundwater Use Dividing into Aquifers

Priority	Borehole Information	Decision of Aquifer	Number of Wells
1	Screen depth	Aquifer in which screen exists	28
2	Borehole depth	Aquifer in which bottom of borehole exists	3,405
3	Water strike depth	Aquifer in which deepest water strike occurred	17
4	Water strike aquifer	Aquifer in which deepest water strike occurred	135
5	No information	Unconfined (Kalahari) Aquifer	1,648
		Total	5,233

Table 12-19 Present Groundwater Use by Aquifer

Use	Unit	Kalahari	Auob	Nossob	Total	%
Domestic	m^3/d	4,426	1,546	483	6,455	15.8
	$1000m^3/a$	1,615	564	176	2,356	
	%	68.6	24.0	7.5	100.0	
Stock Watering	m^3/d	12,580	2,954	55	15,589	38.1
	$1000m^3/a$	4,592	1,078	20	5,690	
	%	80.7	18.9	0.4	100.0	
Irrigation	m^3/d	9,733	9,122	13	18,868	46.1
	$1000m^3/a$	3,553	3,330	5	6,887	
	%	51.6	48.3	0.1	100.0	
Total	m^3/d	26,739	13,622	551	40,912	100.0
	$1000m^3/a$	9,760	4,972	201	14,933	
	%	65.4	33.3	1.3	100.0	

Table 12-20 Estimation Sources of Groundwater Use Variation 1990-1999

Year	Commercial Farms *1)	Communal Land		Stock Watering*8) (m^3/a)	Irrigation*11) (million m^3/a)
		Aminuis*4)	Nama Land*6)		
1989	-	-	-	883,600*9)	-
1990	13,260	7,670	1,800	867,479	2.193018
1991	13,350*2)	7,830*5)	1,850	851,652	2.427783
1992	13,440	8,000	1,910	836,113	2.68768
1993	13,530	8,170	1,960	820,859	2.9754
1994	13,620	8,340	2,010	805,882	3.29392
1995	13,720	8,520	2,070	791,179	-
1996	13,800	8,700	2,130	776,744	-
1997	13,900	8,890	2,190	762,572	-
1998	14,000	9,080	2,250	748,659	-
1999	14,090*3)	9,280	2,310*7)	735,000*10)	-

1) Annual growth 0.68%
2) Population and Housing Census 1991
3) Estimated number based on the Hydrocensus (excluding R0132/A+R0134+R0249/Rem)
4) Annual growth 2.14%
5) From Chap.10
6) Annual growth 2.48%
7) Estimated number based on the Hydorocensus (population of M0120+R0237+M0238)
8) Annual growth −1.82%
9) Based on the Hydrocensus 1986-1989, Area1-3 (Table12-22)
10) Based on the Hydrocensus
11) Exponential function approximation y=2.9754Exp(0.1017x)

Table 12-21 Results of Hydrocensus 1986-1989

		Area 1	Area 2	Area3	Total	
Surveyed Area		5140	8095	7500	20735	
Number of Farms		62	117	99	278	
Number of Wells		563	439	836	1838	
Number of Stocks	Large	8000	-	12000	-	
	Small	122000	-	16000	-	
Irrigation Area (ha)		330.0	13.4	40.0	383.4	
Groundwater Use (m^3/year)	Domestic	200000	700000	530000	1430000	15%
	Stock Water	300000	370000	440000	1110000	12%
	Irrigation	6100000	240000	570000	6910000	73%
	Total	6600000	1310000	1540000	9450000	100%
Aquifer (m^3/year)	Kalahari	400000	710000	1490000	2600000	28%
	Artesian	6200000	600000	50000	6850000	72%

Source: Geohydrology Division, Department of Water Affairs, South West Africa/Namibia, 1986; 1987; 1989

Unit Consumption, Large Stock: 35Liter/d/head, Small Stock: 5Liter/d/head
Irrigation: 50m^3/d/ha (Drip Irrigation 16.7 m^3/d/ha)

Table 12-22 Comparison of Results of Hydrocensus between 1986-1989 and 1999

1986-1989 (A)	Area1	Area2	Area3	Total
Farms	55	68	72	195
Wells	505	323	636	1464
Irrigation Area (ha)	320.8	21.3	16.5	358.6
Drip Irrigation Area (ha)				
Domestic Use (m^3/a)	216200	396600	499000	1111800
Stock Water (m^3/a)	271900	234800	376900	883600
Irrigation Use (m^3/a)	5853700	389500	300200	6543400
Total (m^3/a)	6341800	1020900	1176100	8538800
1999 (B)	Area1	Area2	Area3	Total
Farms	99	73	89	261
Wells	497	342	721	1560
People	1815	795	1077	3687
Large Stock	3750	4964	4950	13664
Small Stock	95928	91605	120306	307839
Irrigation Area (ha)	408.7	40.0	31.8	480.5
Production of Permit Holders (m^3/a) 1)	1090991	69136	0	1160127
Converted Irrigation Area (ha) 2)	72.9	4.6	0.0	77.5
Total (ha)	481.6	44.6	31.8	558.0
Drip Irrigation Area (ha	110.0	2.0	18.0	130.0
Domestic Use (m^3/a)	248800	205700	159500	614000
Stock Water (m^3/a)	221600	230600	282800	735000
Irrigation Use (m^3/a) 3)	8789200	813950	580350	10183500
Irrigation Use (m^3/a) 4)	7450867	705700	360400	8516967
Total -1 (m^3/a) 5)	7921267	1142000	802700	9865967
Total -2 (m^3/a) 6)	9259600	1250250	1022650	11532500
Farms (B)/(A)	180%	107%	124%	134%
Wells (B)/(A)	98%	106%	113%	107%
Irrigated Area (B)/(A)	150%	209%	193%	156%
Domestic Use (B)/(A)	115%	52%	32%	55%
Stock Water (B)/(A)	82%	98%	75%	83%
Irrigation Use (B)3)/(A)	150%	209%	193%	156%
Irrigation Use (B)4)/(A)	127%	181%	120%	130%
Total-1/(A)	125%	112%	68%	116%
Total-2/(A)	146%	122%	87%	135%

1) Farms without Hydrocensus record, but with permit

2) Using unit consumption of 41m^3/d/ha

3) Unit consumption: 50m^3/d/ha

4) Unit consumption: 50m^3/d/ha, Drip Irrigation: 16.7m^3/d/ha

5) Using Irrigation use 4)

6) Using Irrigation use 3)

Table 12-23 Variation of Groundwater Use

Year	Domestic Use (m^3/day)				Stock Watering (m^3/day)				Irrigation Use (m^3/day)				Groundwater Use (m^3/day)			
	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Total
1990	4228	1219	492	5939	14848	3486	65	18398	3856	3614	5	7475	22931	8319	561	31812
1991	4205	1180	474	5859	14577	3422	63	18063	4269	4001	6	8275	23051	8603	542	32196
1992	4201	1252	628	6081	14311	3360	62	17733	4726	4429	6	9161	23238	9041	696	32975
1993	4132	1237	629	5998	14050	3299	61	17410	5231	4903	7	10141	23413	9439	697	33549
1994	4210	1208	667	6086	13793	3239	60	17092	6157	5149	8	11313	24161	9596	735	34491
1995	4340	1262	562	6164	13542	3179	59	16780	7216	5881	9	13106	25098	10323	630	36051
1996	4365	1160	553	6078	13295	3121	58	16474	9626	6758	11	16396	27285	11040	621	38947
1997	4305	1201	553	6059	13052	3065	57	16173	8215	5657	9	13881	25572	9923	619	36114
1998	4344	1598	406	6348	12814	3009	56	15878	10307	8543	13	18862	27464	13150	474	41088
1999	4426	1546	483	6455	12580	2954	55	15589	9733	9122	13	18868	26739	13622	551	40912

Year	Domestic Use (1000m^3/year)				Stock Watering (1000m^3/year)				Irrigation Use 1000(m^3/year)				Groundwater Use (1000m^3/year)			
	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Subtotal	Kalahari	Auob	Nossob	Total
1990	1543	445	180	2168	5419	1272	24	6715	1407	1319	2	2728	8370	3037	205	11611
1991	1535	431	173	2138	5321	1249	23	6593	1558	1460	2	3020	8413	3140	198	11752
1992	1533	457	229	2220	5223	1226	23	6473	1725	1617	2	3344	8482	3300	254	12036
1993	1508	452	230	2189	5128	1204	22	6354	1909	1790	2	3702	8546	3445	254	12245
1994	1537	441	243	2221	5035	1182	22	6239	2247	1879	3	4129	8819	3503	268	12589
1995	1584	461	205	2250	4943	1161	21	6125	2634	2147	3	4784	9161	3768	230	13158
1996	1593	424	202	2218	4853	1139	21	6013	3514	2467	4	5984	9959	4030	227	14216
1997	1571	438	202	2212	4764	1119	21	5903	2998	2065	3	5067	9334	3622	226	13181
1998	1586	583	148	2317	4677	1098	20	5796	3762	3118	5	6885	10025	4800	173	14997
1999	1615	564	176	2356	4592	1078	20	5690	3553	3330	5	6887	9760	4972	201	14933