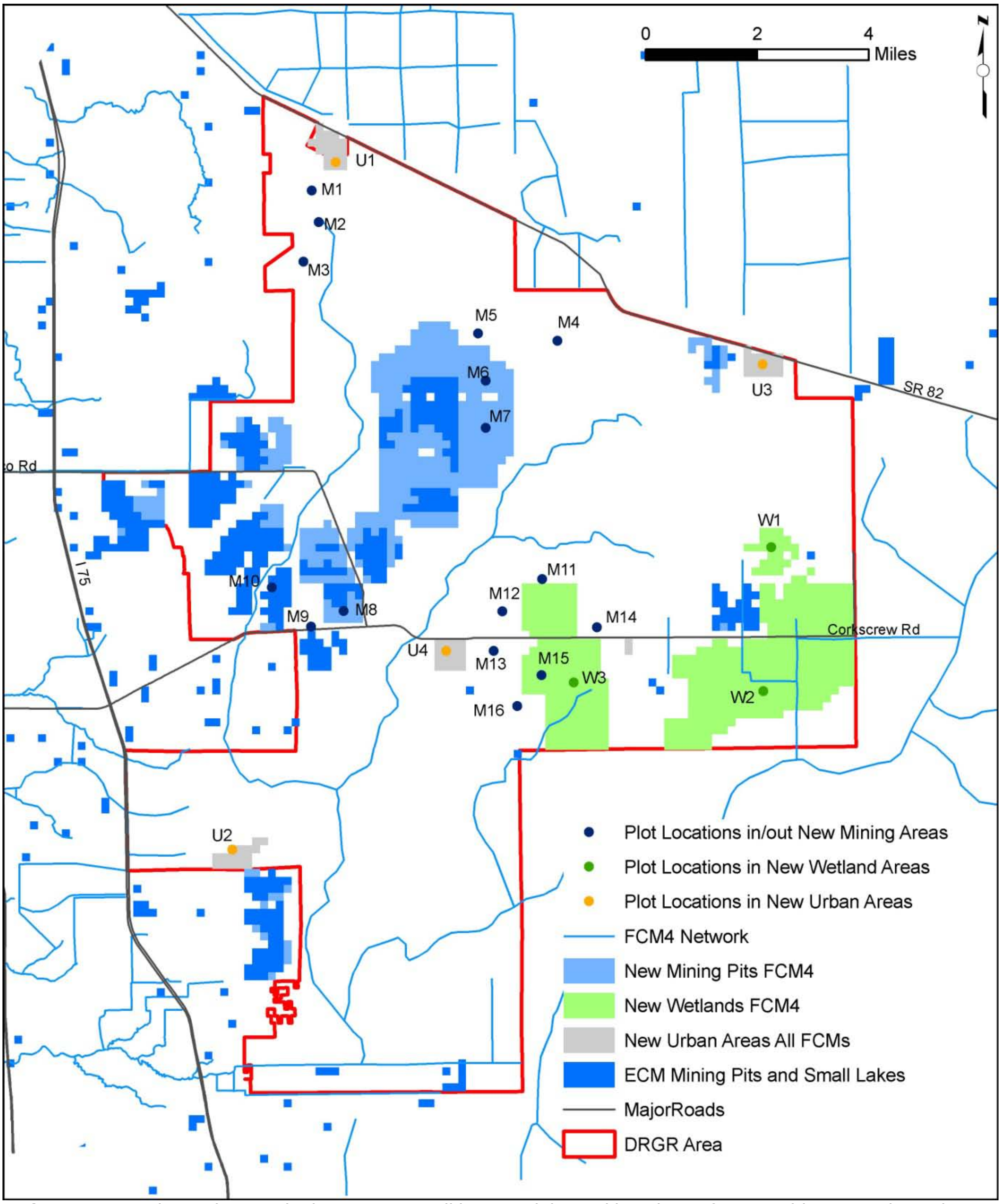

Figure 46. Land use changes in the Future Conditions Model 4 and locations of water table comparison plots.

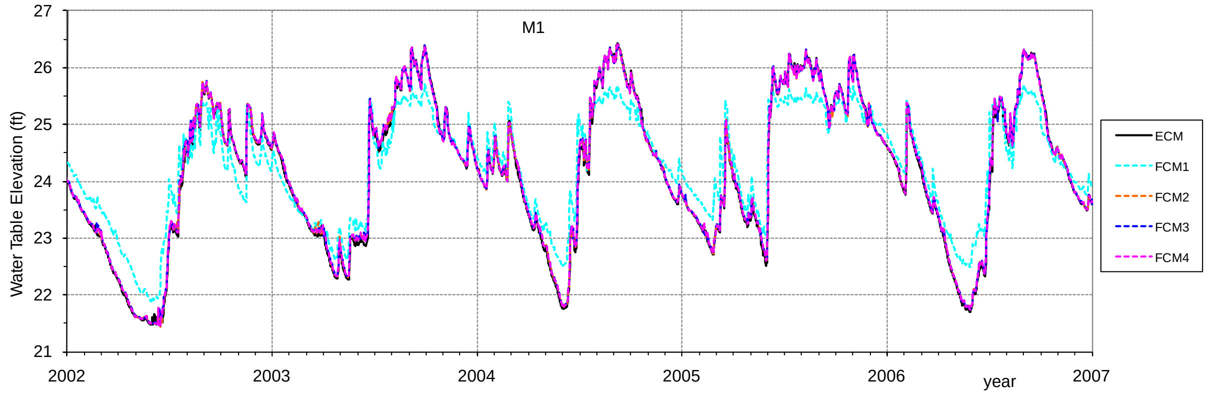

Figure 47. Water table elevations at land use change location M1.

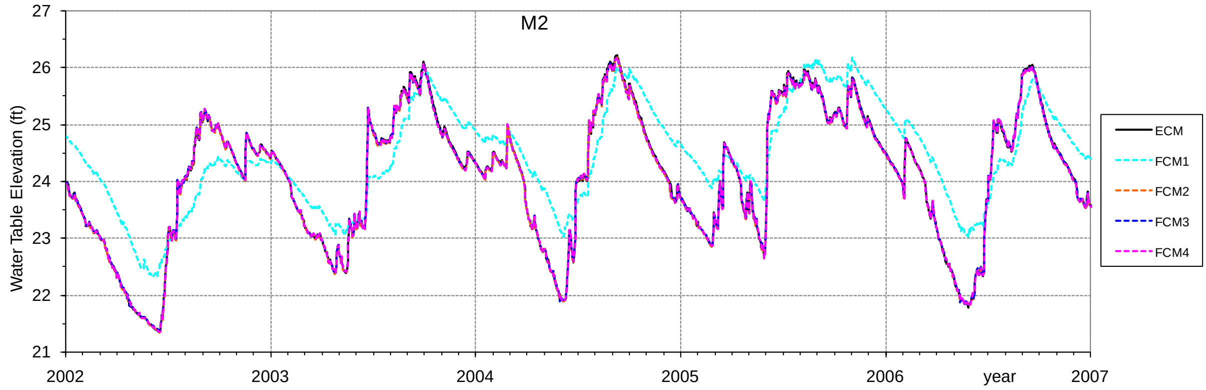

Figure 48. Water table elevations at land use change location M2.

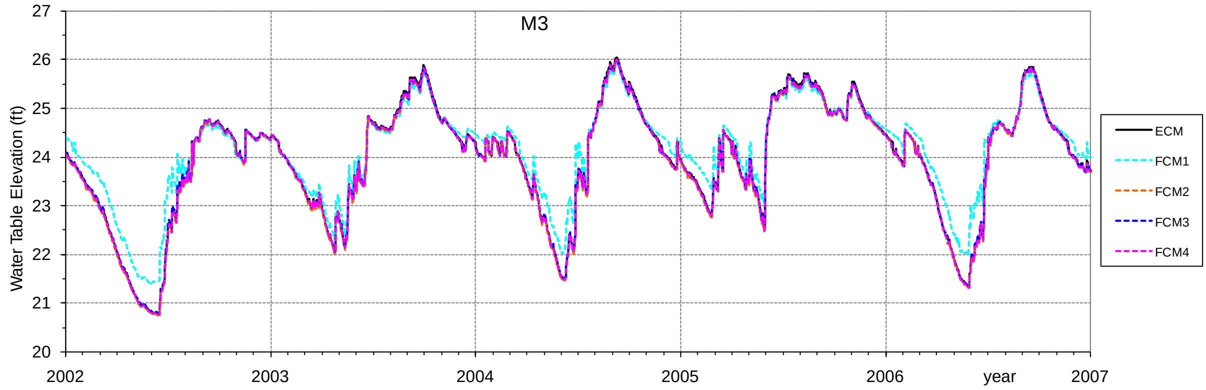

Figure 49. Water table elevations at land use change location M3.

Note: Locations M1 and M3 are close to a new mining pit included in FCM1 and location M2 is inside it. The model predicts that this mining pit recharges the groundwater such that the water table elevation (WTE) in neighboring areas increases during dry periods compared to the ECM. WTE oscillation in location M2 shows a reduction in the seasonal amplitude when located in a mining pit. The corresponding seasonal averaged plots are shown in Figure 70.

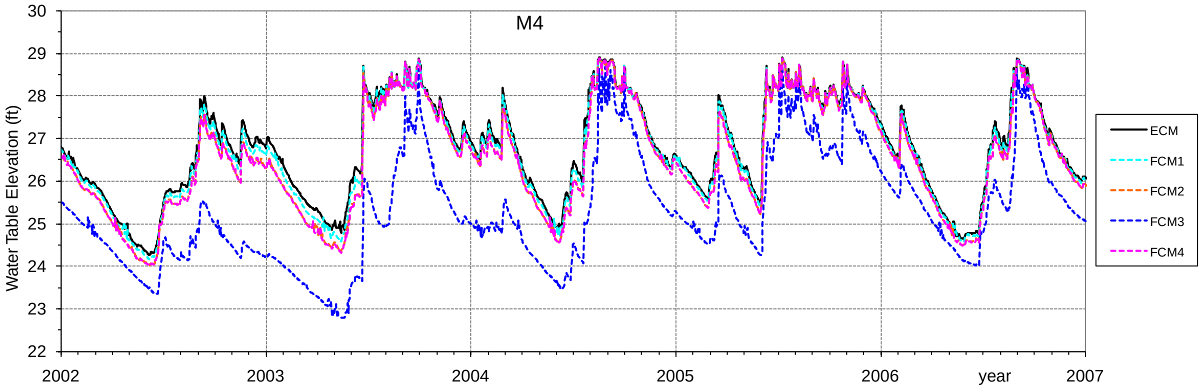

Figure 50. Water table elevations at land use change location M4.

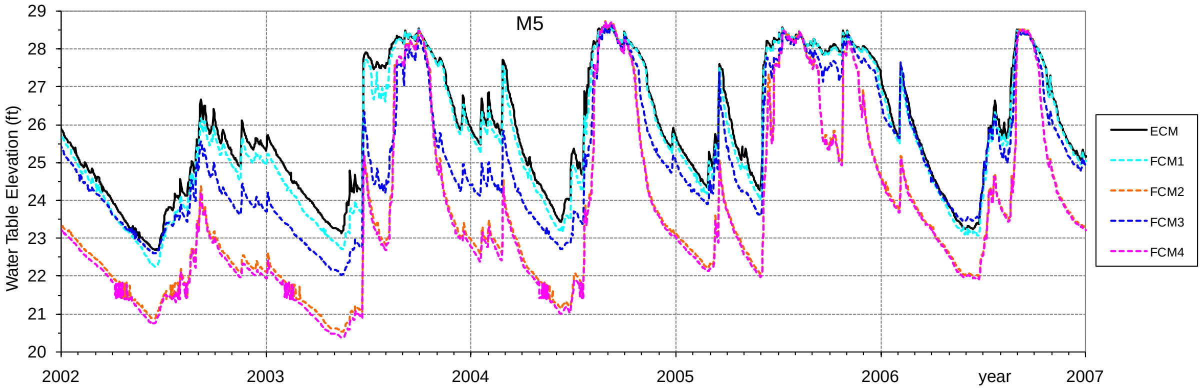

Figure 51. Water table elevations at land use change location M5.

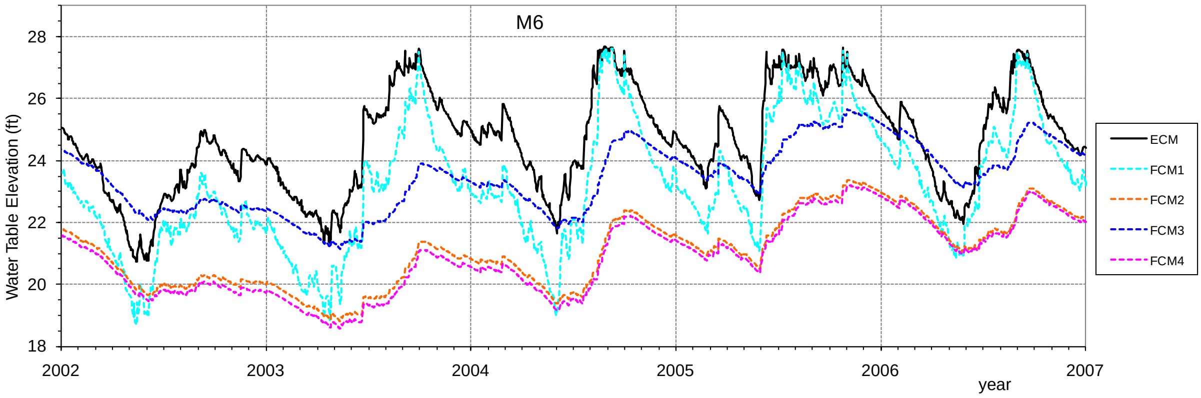

Figure 52. Water table elevations at land use change location M6.

<u>Note:</u> Locations M4, M5, M6 and M7 show that the new mining pit area in the FCMs generally causes a WTE decrease in the northern–central part of the DR/GR Area. This area is up gradient of the large mining pit complex area. WTE oscillation in locations M6 and M7 indicate a reduction in the seasonal amplitude when they become part of a mining pit.

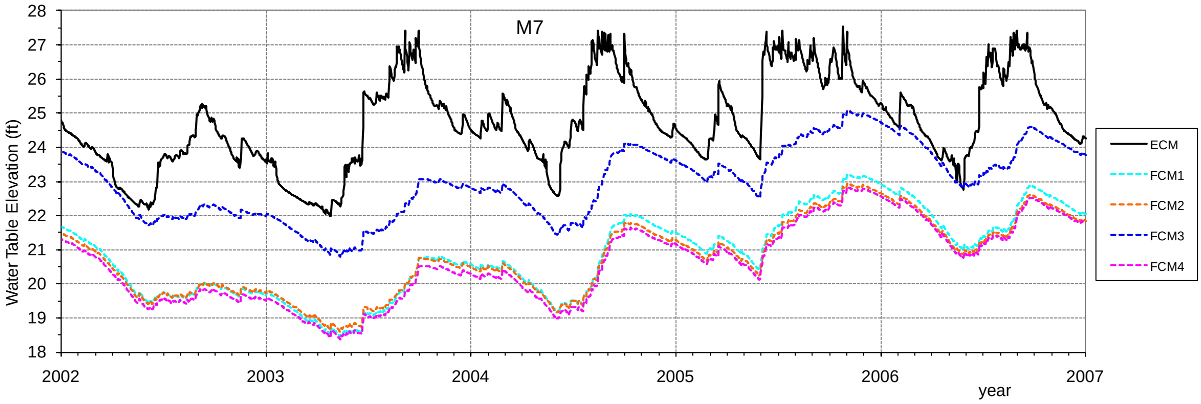

Figure 53. Water table elevations at land use change location M7.

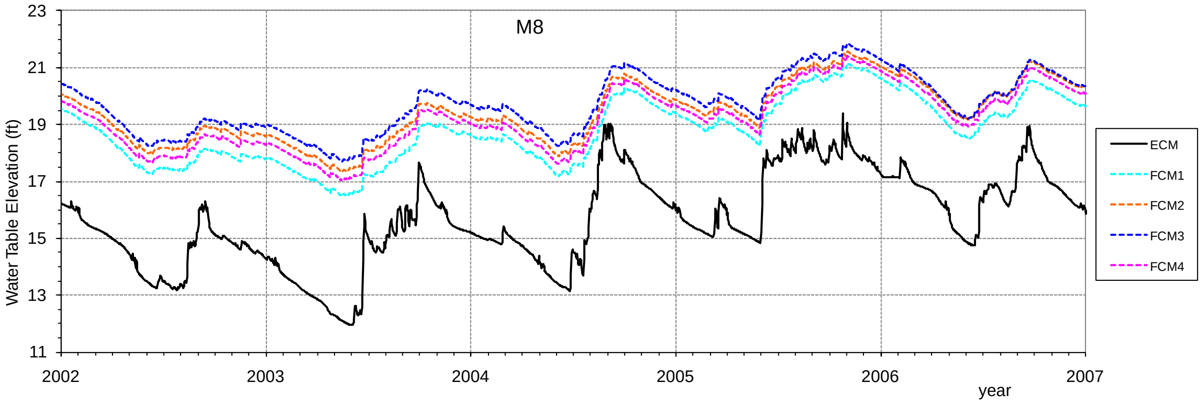

Figure 54. Water table elevations at land use change location M8.

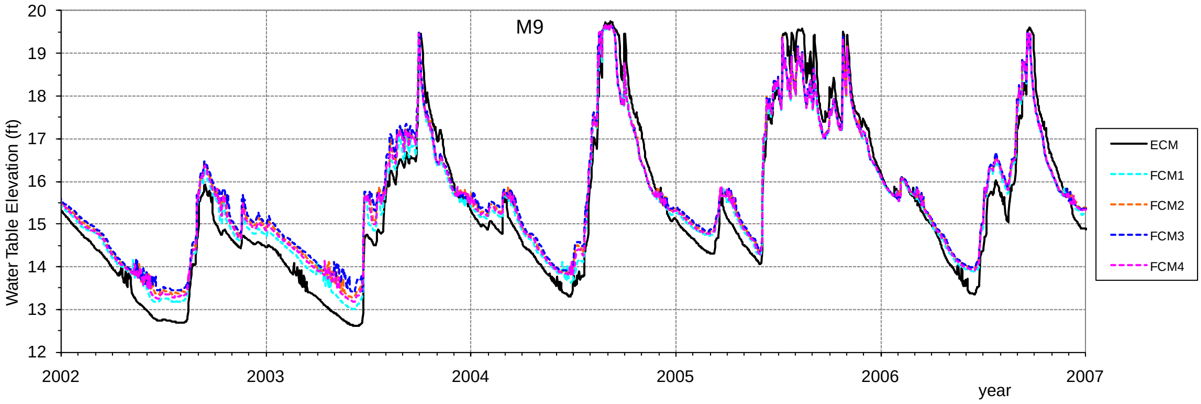

Figure 55. Water table elevations at land use change location M9.

Note: Locations M8, M9, and M10 show that the new mining pit area in the FCMs generally cause a WTE increase in the western-central part of the DR/GR Area. This area is down gradient of the large mining pit complex area. The WTE oscillation in location M8 is reduced in seasonal amplitude when it becomes part of a mining pit.

Figure 56. Water table elevations at land use change location M10.

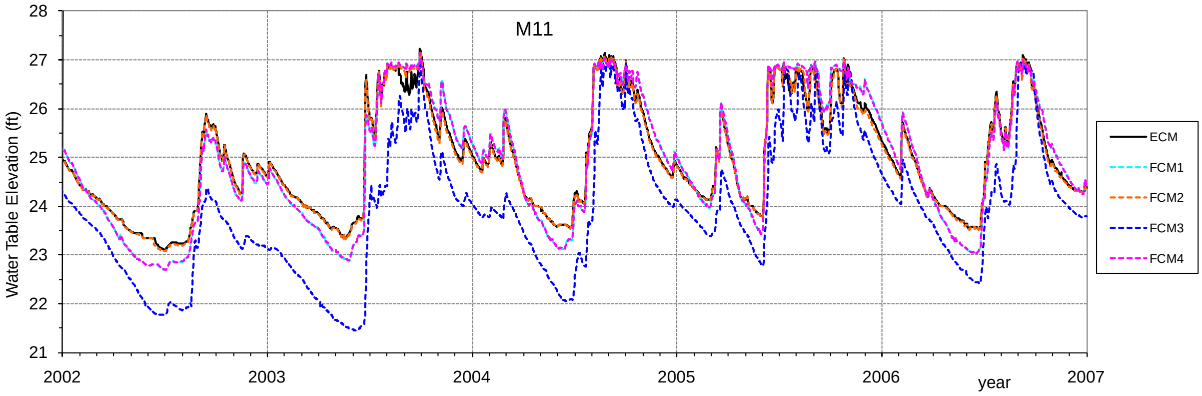

Figure 57. Water table elevations at land use change location M11.

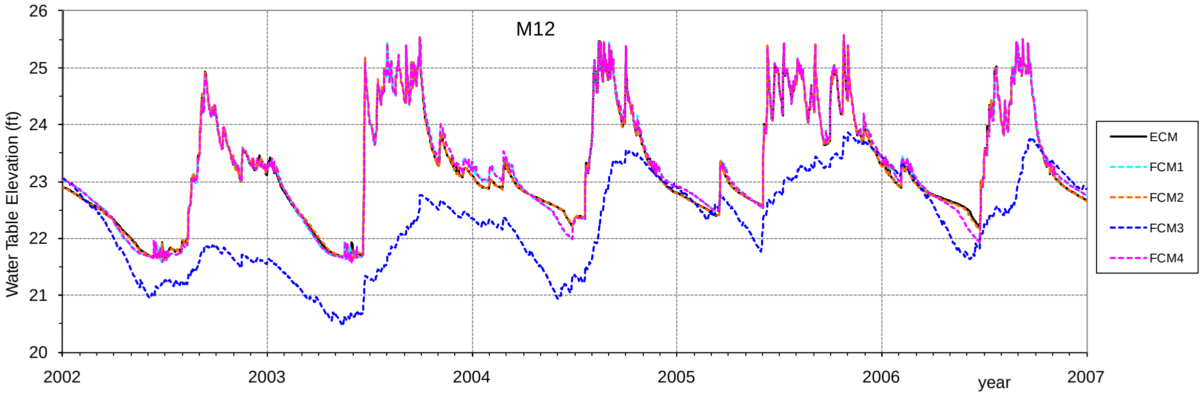

Figure 58. Water table elevations at land use change location M12.

<u>Note:</u> Location M11 shows a dry-season WTE oscillation decrease in FCM3. This is likely due to the mining pit down gradient of this location. M12 has a reduction in seasonal WTE oscillation amplitude when it becomes part of the mining pit in FCM3.

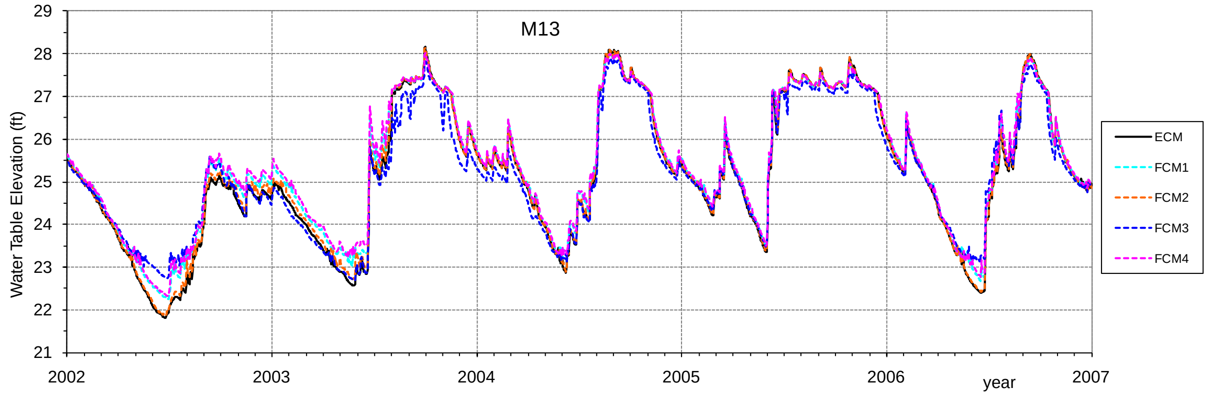

Figure 59. Water table elevations at land use change location M13.

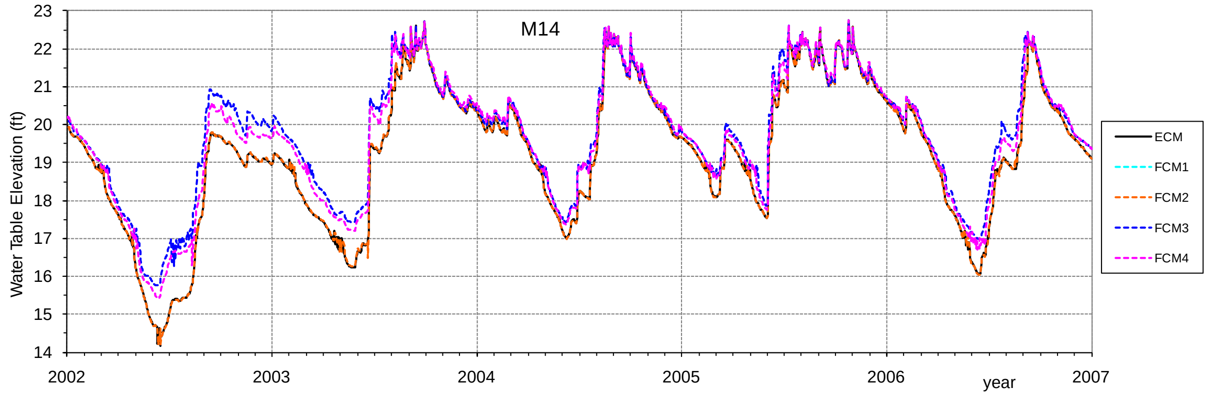

Figure 60. Water table elevations at land use change location M14.

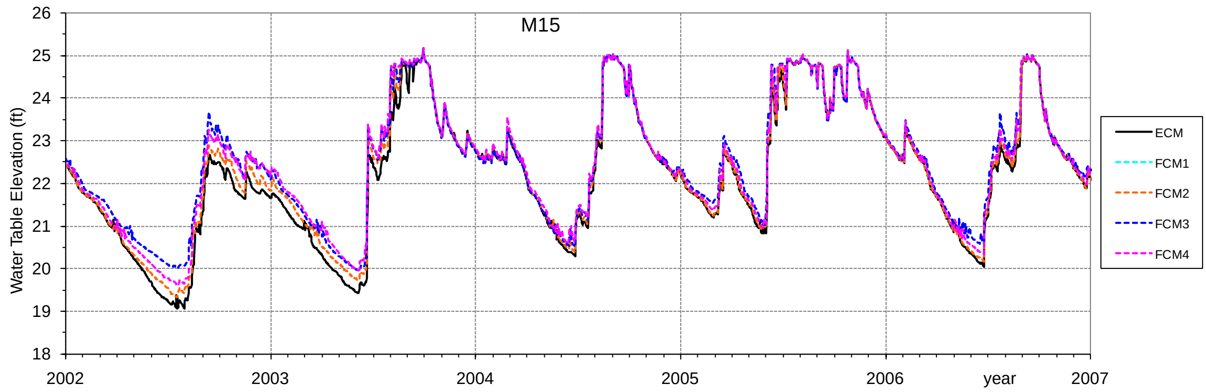

Figure 61. Water table elevations at land use change location M15.

Note: Locations M13, M14, M15 and M16 show a dry-season WTE increase in FCM3 due to the combined effects of the new mining pit and wetland areas. There is also a dry-season WTE increase in FCM1 and FCM4 due to new wetland areas. M15 shows a reduction of the seasonal oscillation amplitude when it becomes part of the mining pit in FCM3.

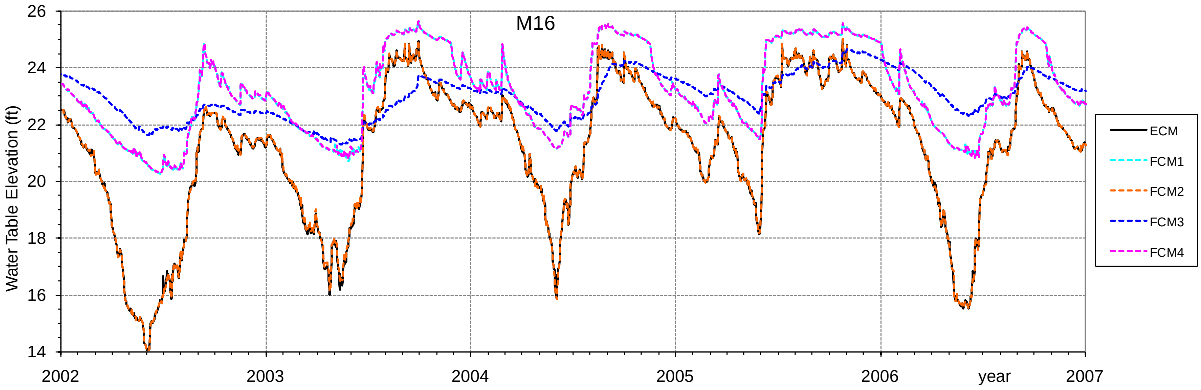

Figure 62. Water table elevations at land use change location M16.

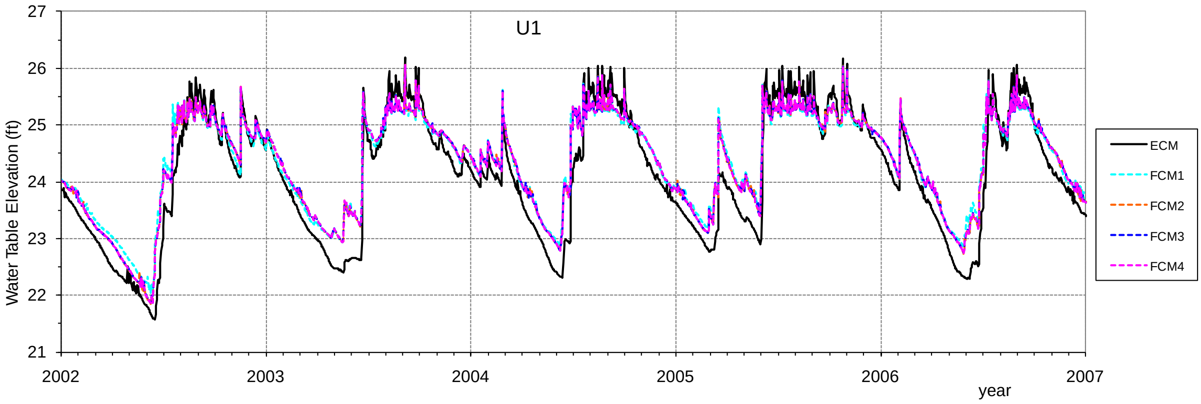

Figure 63. Water table elevations at land use change location U1.

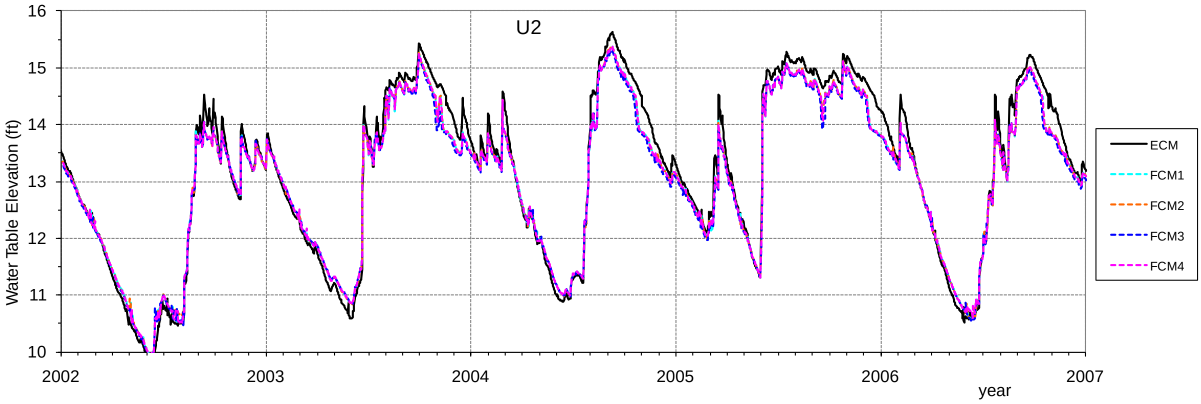

Figure 64. Water table elevations at land use change location U2.

Note: Locations U1, U2, and U3 show a decrease in wet-season WTEs, likely due to the new urban area drainage.

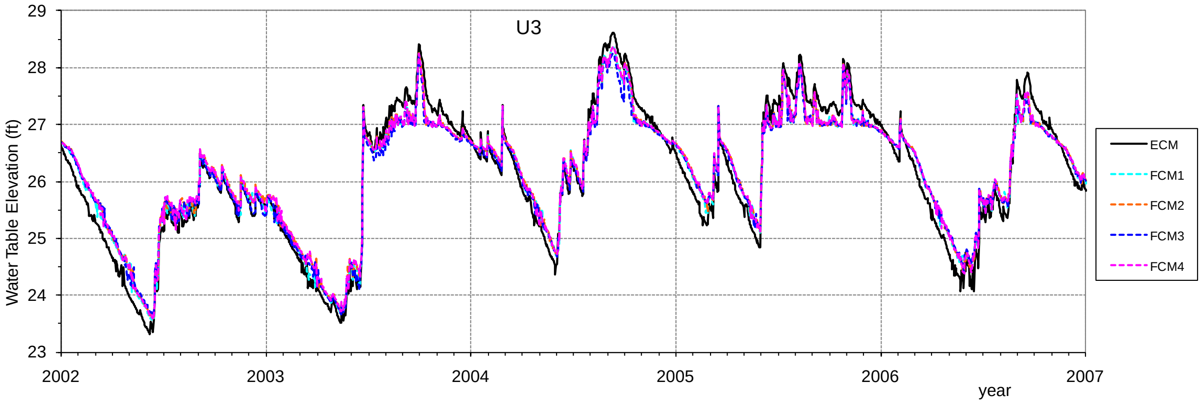

Figure 65. Water table elevations at land use change location U3.

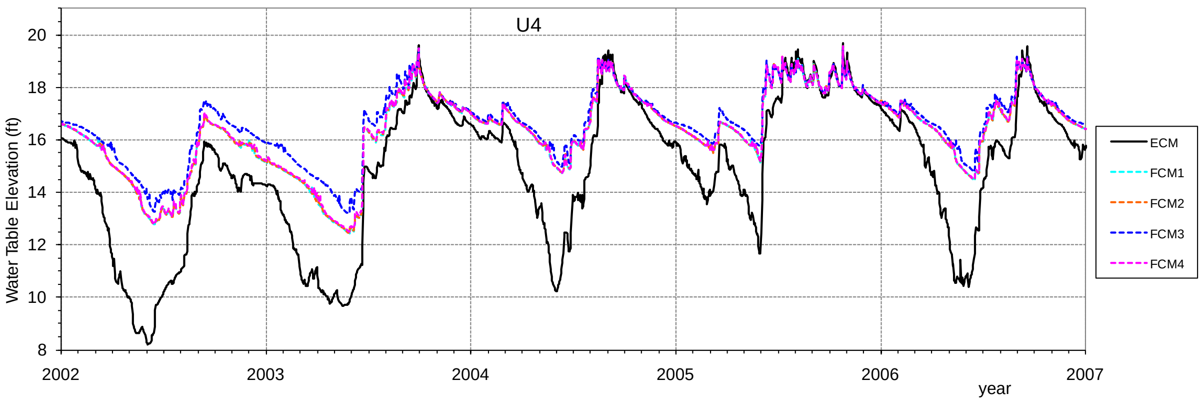

Figure 66. Water table elevations at land use change location U4.

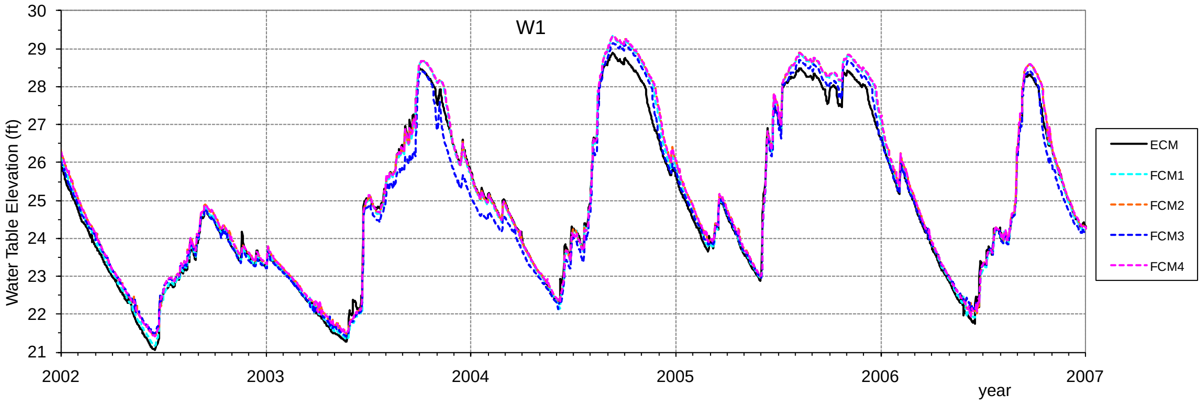

Figure 67. Water table elevations at land use change location W1.

Note: Locations U1, U3, and U4 show a dry-season WTE increase in all FCMs.. Location W1 shows small WTE differences after the small wetland area was added in all FCMs.

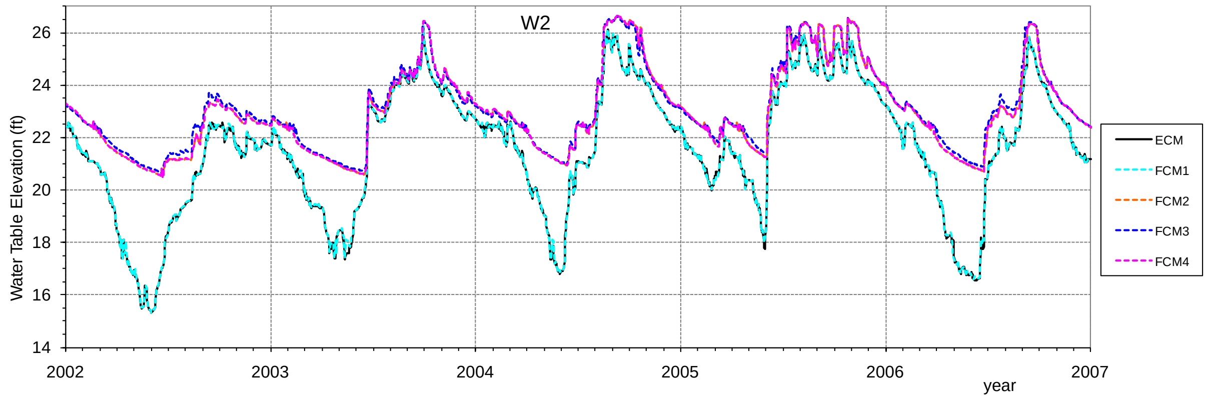

Figure 68. Water table elevations at land use change location W2.

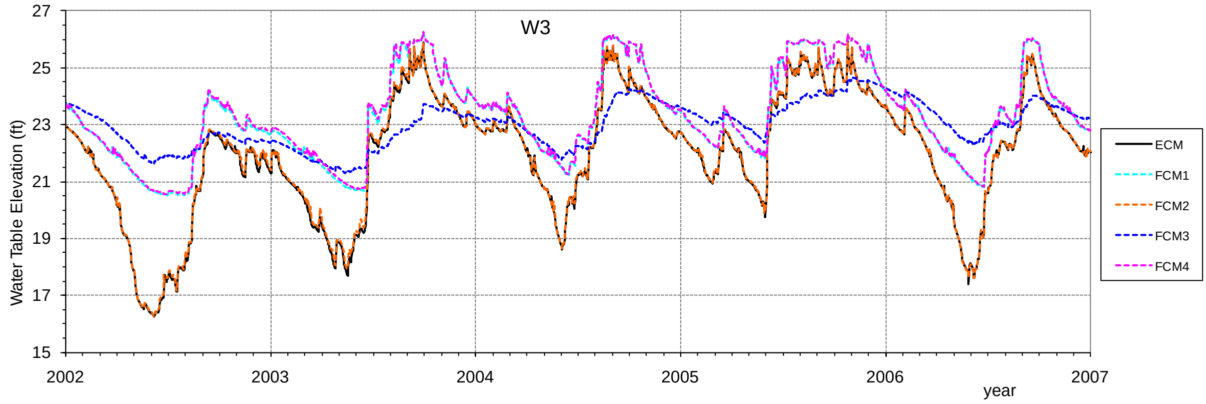

Figure 69. Water table elevations at land use change location W3.

<u>Note:</u> Location W2 shows a dry-season WTE increase due to new wetland areas added in FCM2, FCM3, and FCM4. Location W3 shows a dry-season WTE increase due to new wetland areas added in FCM1 and FCM4, and the combination of new mining pit and wetland areas in FCM3.

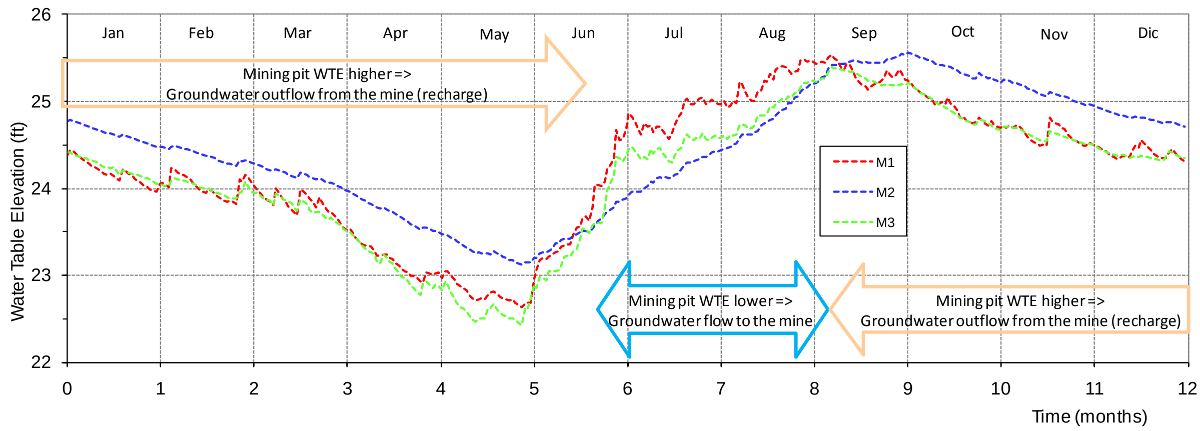

Figure 70. Seasonal averaged water table elevation at locations M1, M2 and M3 in FCM1.

Water Table Maps

Water table elevation maps obtained from all the FCMs are presented in Appendix G. Those maps are extracted from the different models at the end of the dry and the wet season (i.e., the ten last days of May and the ten last days of September, respectively). **Figure 72** to **Figure 79** show water table difference maps for all future condition scenarios in relation to the LS ECM for both the wet and dry seasons.

The most significant changes in the water table are observed in the large mining pit complex of the DR/GR Area. In the future conditions scenarios, the area occupied by mining pits increases, the distance between neighboring mining pits decreases, and they become more hydrologically connected (i.e. via groundwater). Consequently, the water table elevation decreases in up-gradient areas and increases down gradient. The down gradient effect is bigger in the dry season than in the wet season.

A conceptual model of the flattening effect of a single mining pit on the water table elevation is sketched in **Figure 71**. The model predicts that the mine flattens the water table commonly causing a decrease in groundwater levels up gradient with respect to the pre-mining conditions. Down gradient of the mining pits, this effect may produce either an increase or a decrease in groundwater levels, depending on the local hydrologic conditions, the time of the year, etc. These effects in the upstream and downstream areas are more pronounced in the model in areas with steeper topographic slopes and for larger area mine footprints.

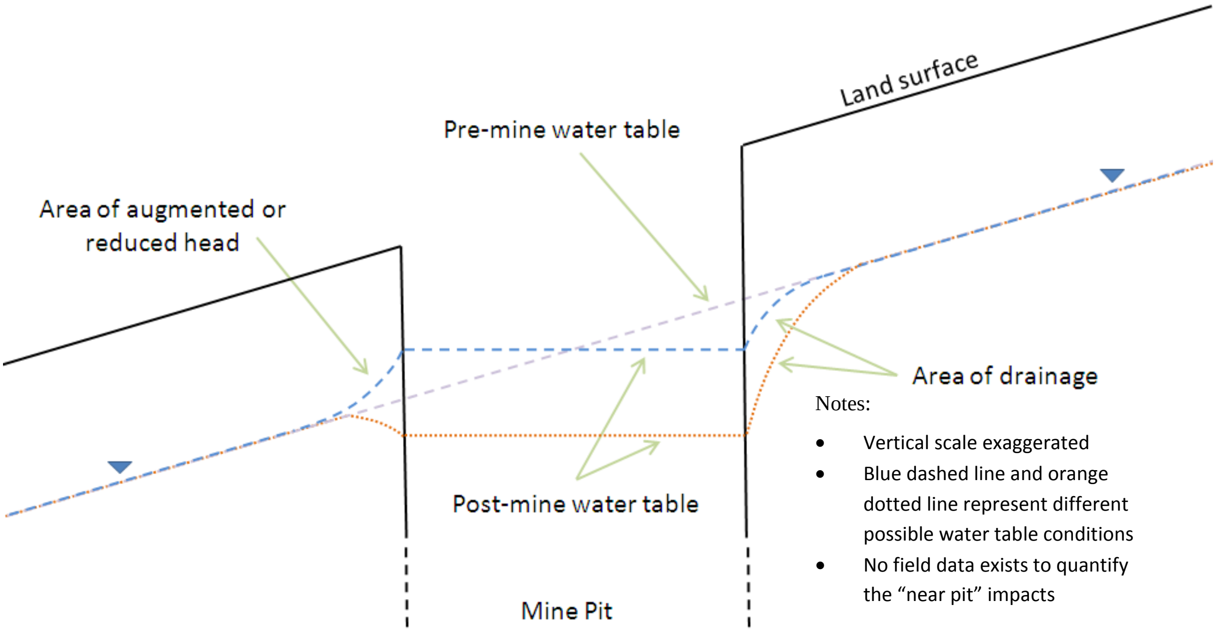

Figure 71. Sketch of the flattening effect on the water table elevation of a mining pit in the presence of a regional gradient.

In the case of the large mining pit complex of the DR/GR Area, there are several mines that are hydrologically connected to some extent. The water table profiles from **Figure 80** through **Figure 83** show that the flattening effect in the water table of the entire mining pit complex area becomes more important in the future condition scenarios as the groundwater connectivity between mines increases. In other words, the groundwater connectivity between mines and therefore the flattening effect increases once land between existing pits is also mined.

The flattening effect was also noticeable at a mine proposed in FCM3 at the central part of the DR/GR Area (see Figure 76 and Figure 77). In this case, the mining pit length is smaller than the length of the mining pit complex, but it was located in an area with a steep water table gradient, as can be seen in Figure 28 and Figure 29. The upstream decrease in the WTE is also observed at location M11 presented in Figure 57.

The mine proposed in the FCM1 at the north-western corner of the DR/GR Area does not cause a flattening effect because it is located in a relatively flat area. In this case, the model predicts that the mining pit maintains a higher water table elevation at the end of the dry season around the pit perimeter (see Figure 72). The higher water table elevation here is presented with respect to the LS ECM, where there are not any pits present. This result cannot be extrapolated to mines in other areas in the DR/GR since the rainfall rate in that mine area is much higher than the average rainfall rate in the entire DRGR (see Water Budget section).

The water table in the new wetland areas increases, in general, due to the removal of the drainage system from when it was an agricultural area. Differences in the water table in the new wetland areas are in general greater at the end of the dry season.

The water table in the new urban areas is usually higher at the end of the dry season compared to the existing conditions. This is likely related to a reduction in the ET losses (see more details in the water budget section).

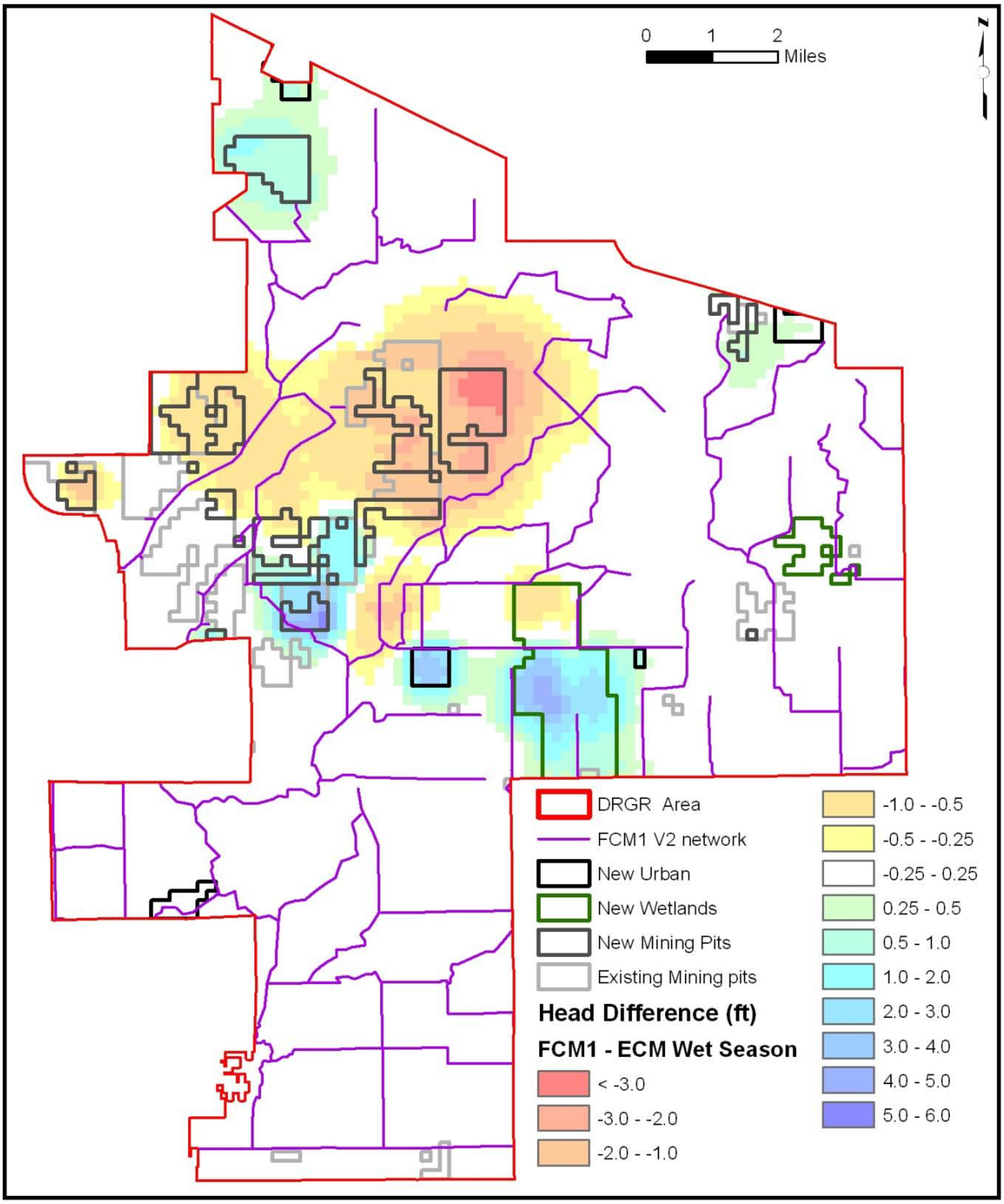

Figure 72. Difference in dry season water table in FCM1 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM1).

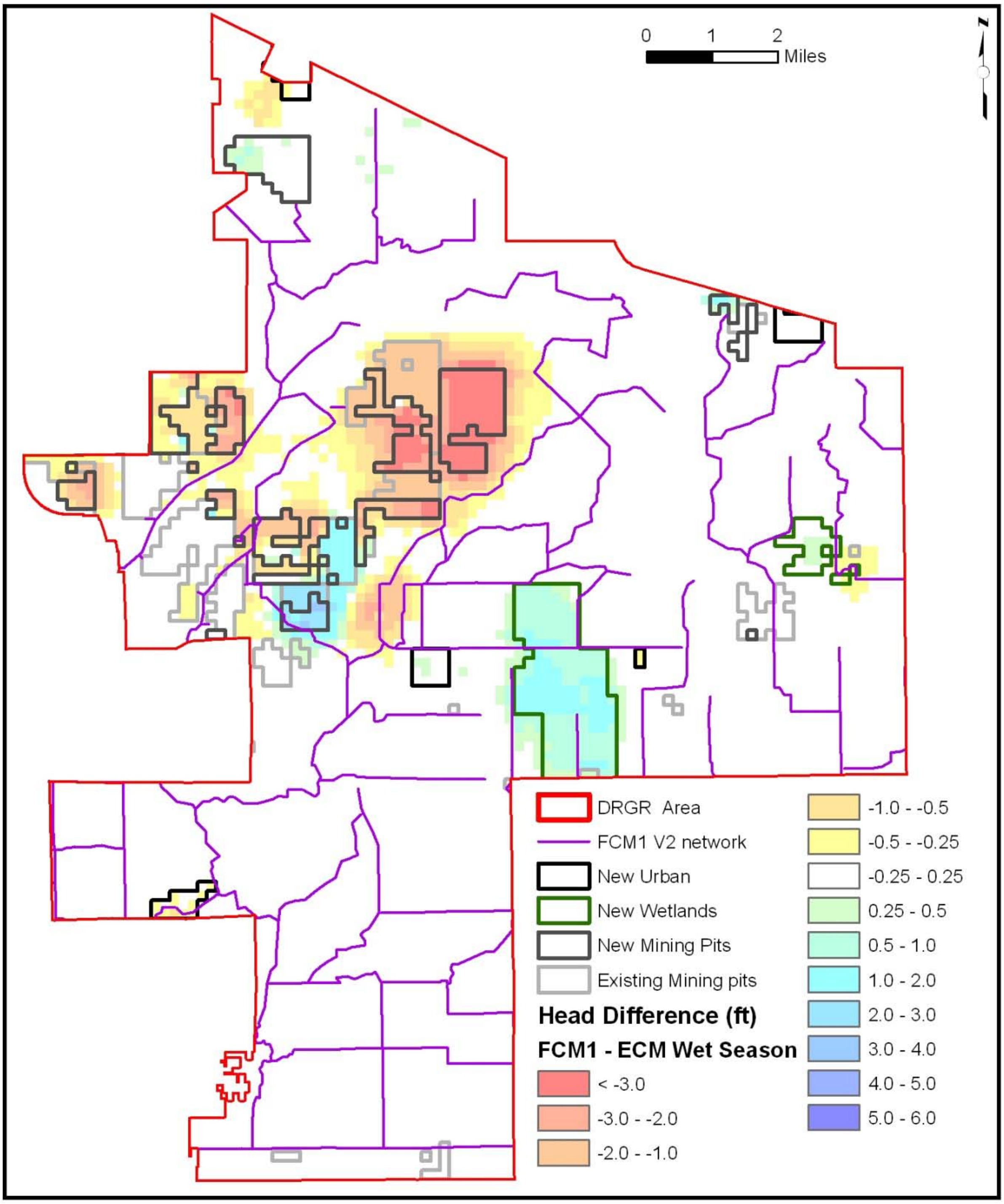

Figure 73. Difference in wet season water table in FCM1 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM1).

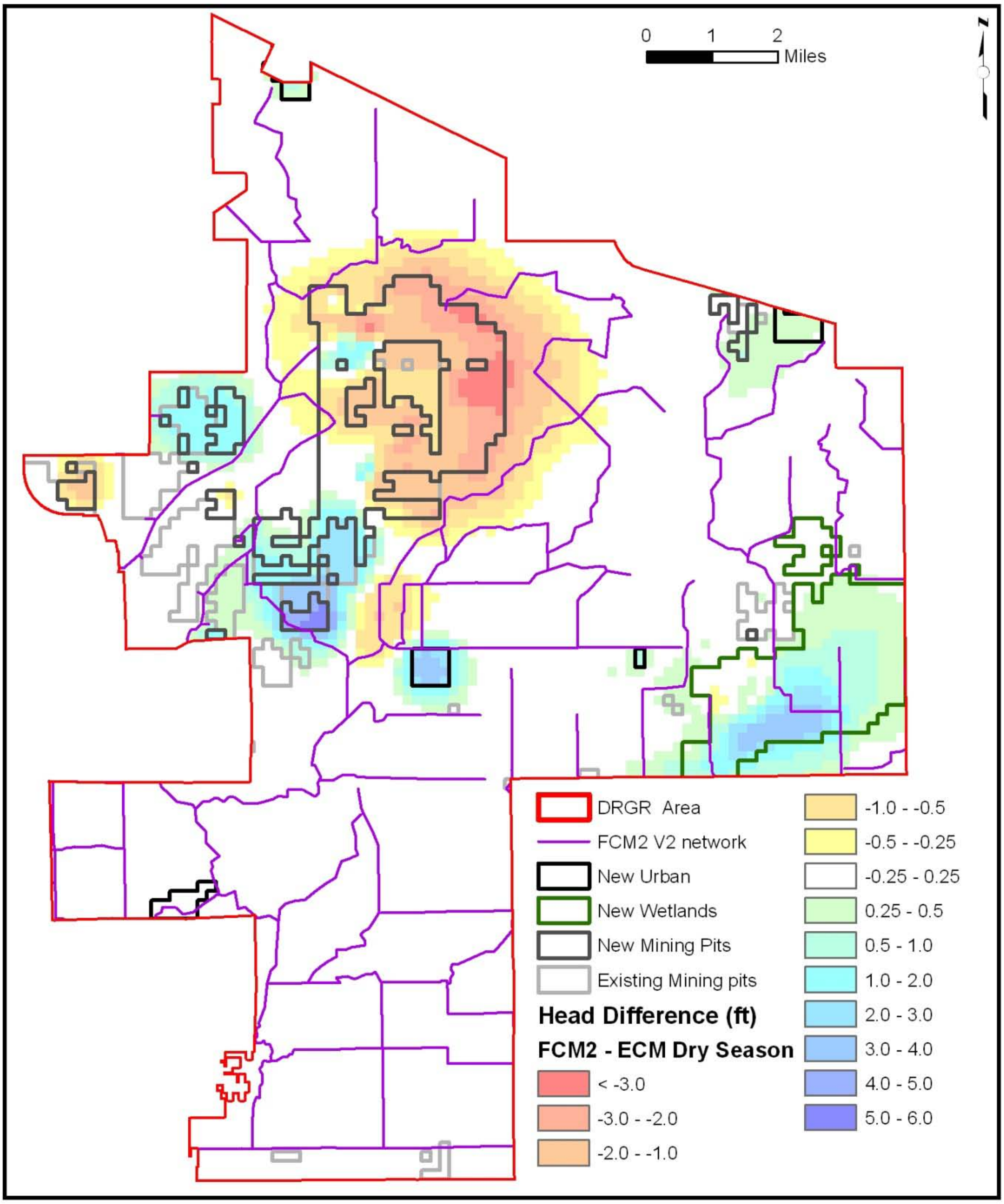

Figure 74. Difference in dry season water table in FCM2 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM2).

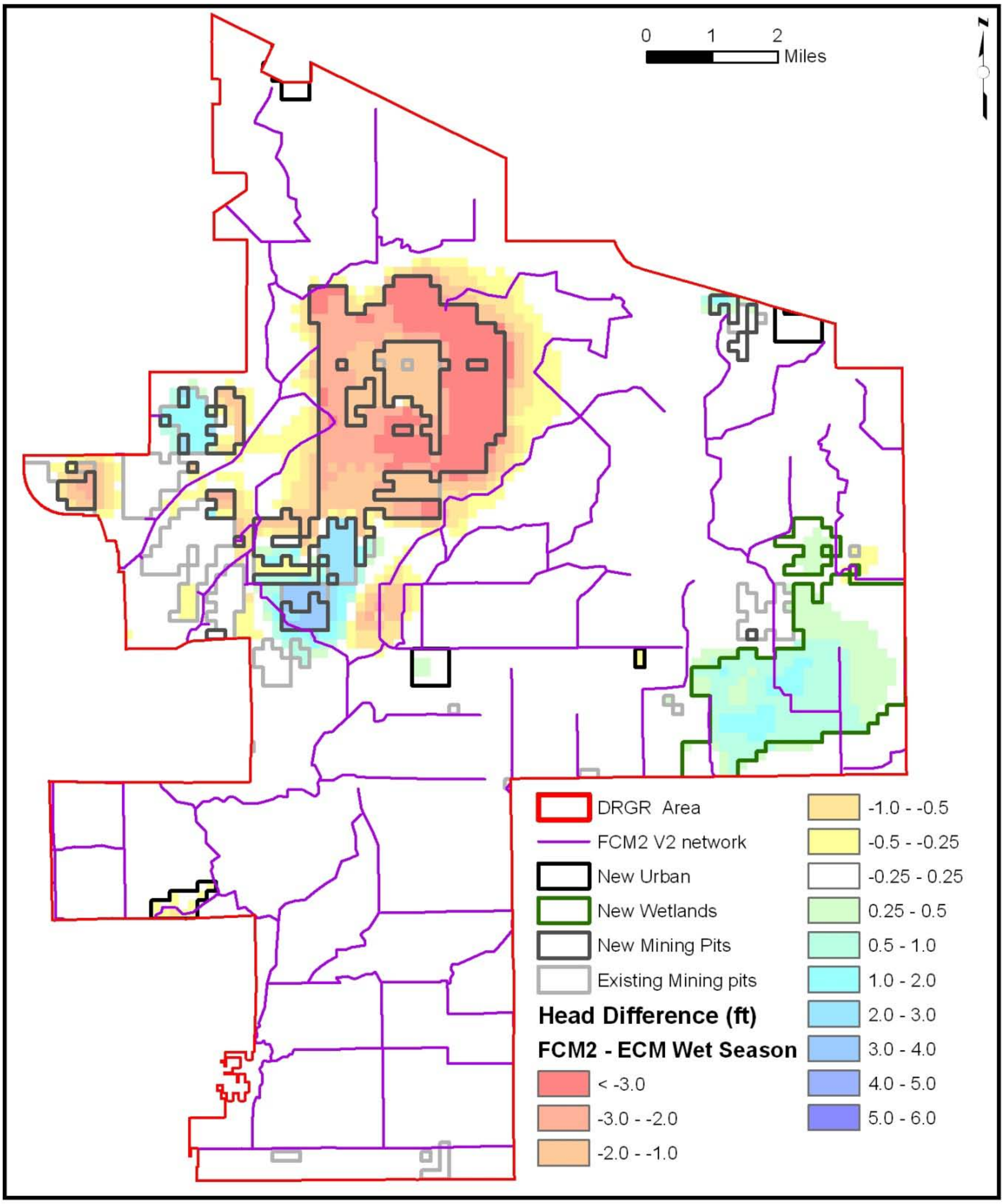

Figure 75. Difference in wet season water table in FCM2 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM2).

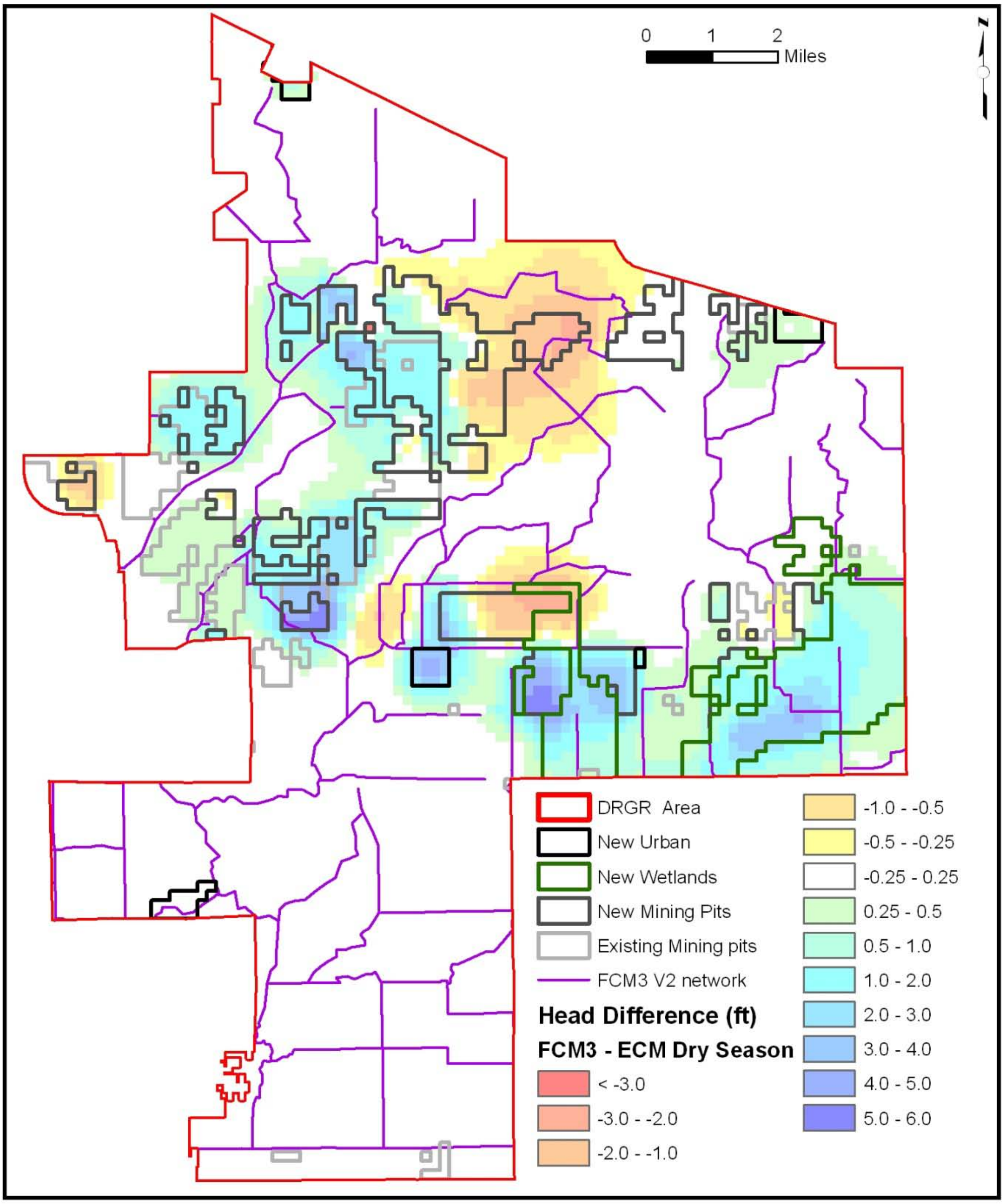

Figure 76. Difference in dry season water table in FCM3 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM3).

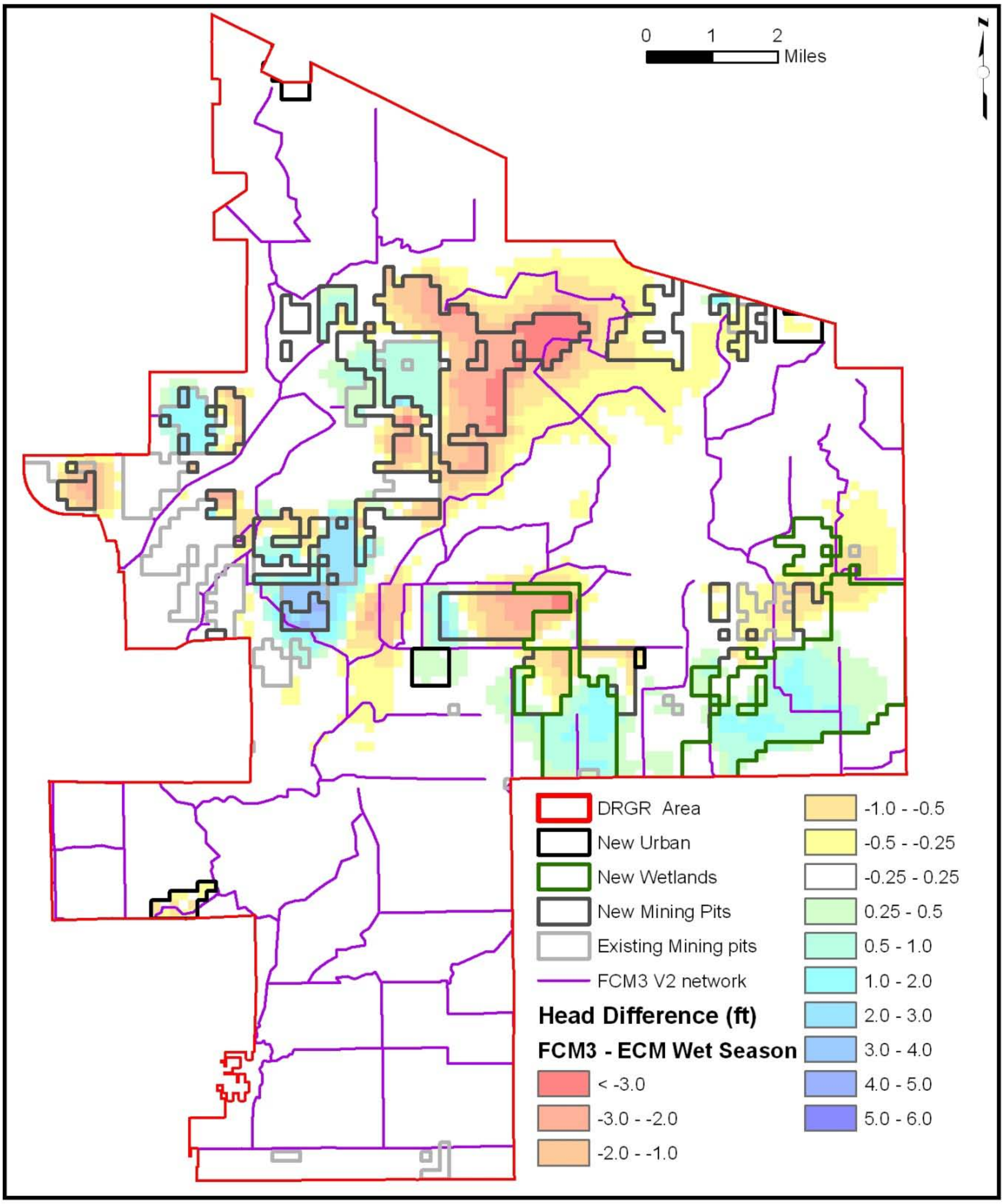

Figure 77. Difference in wet season water table in FCM3 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM3).

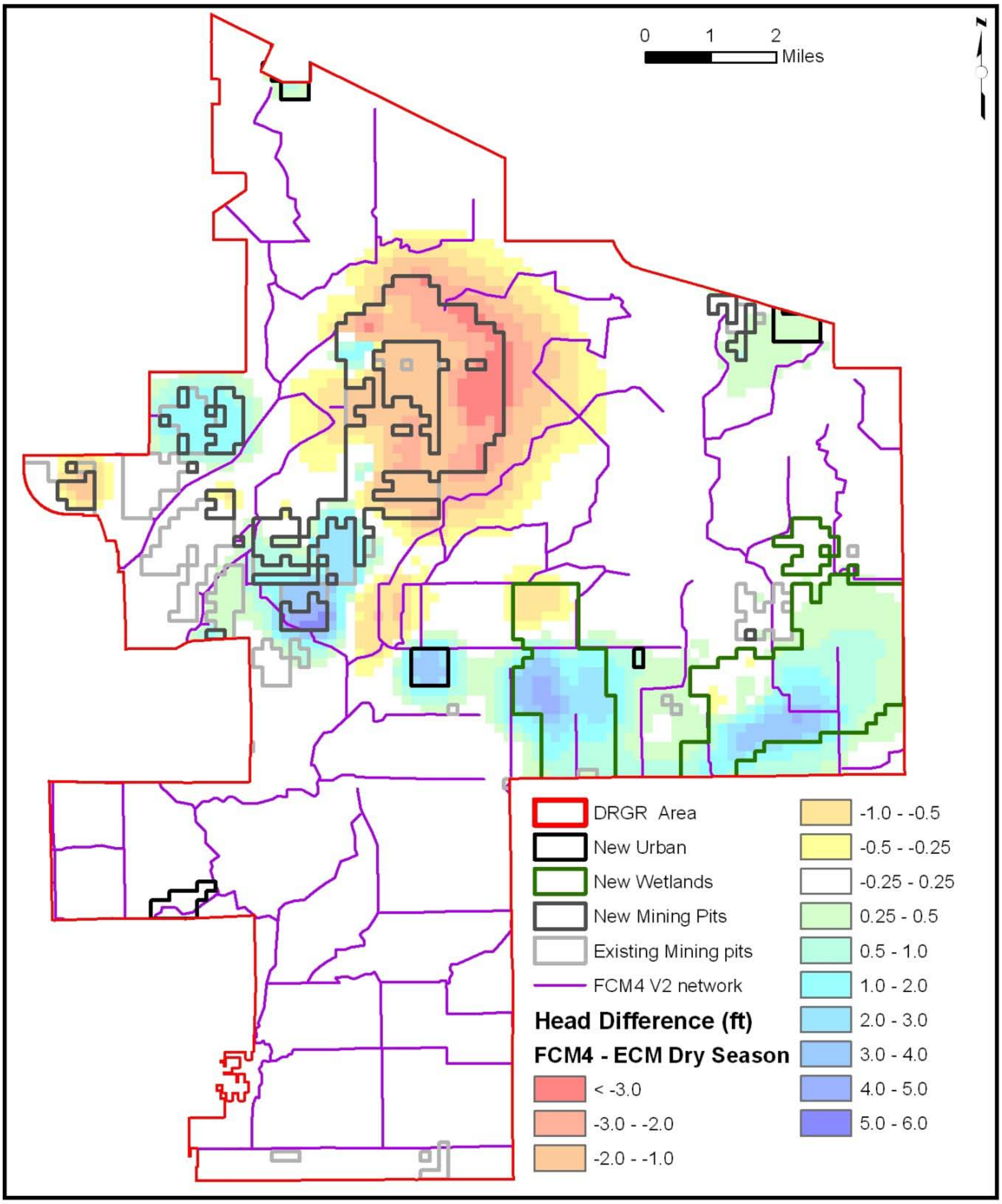

Figure 78. Difference in dry season water table in FCM4 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM4).

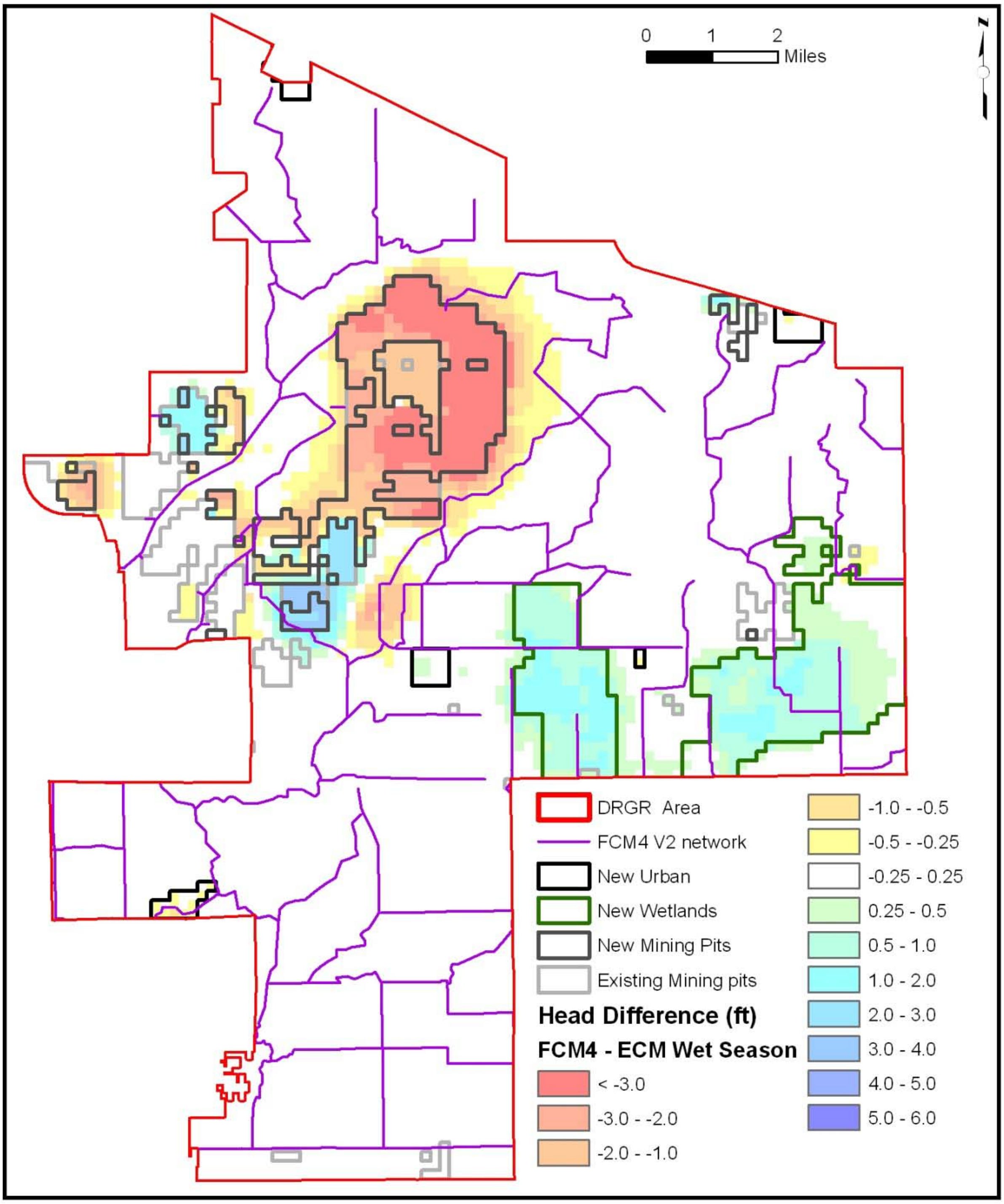

Figure 79. Difference in wet season water table in FCM4 in relation to the LS ECM (Positive values indicate increase in water table elevation in the FCM4).

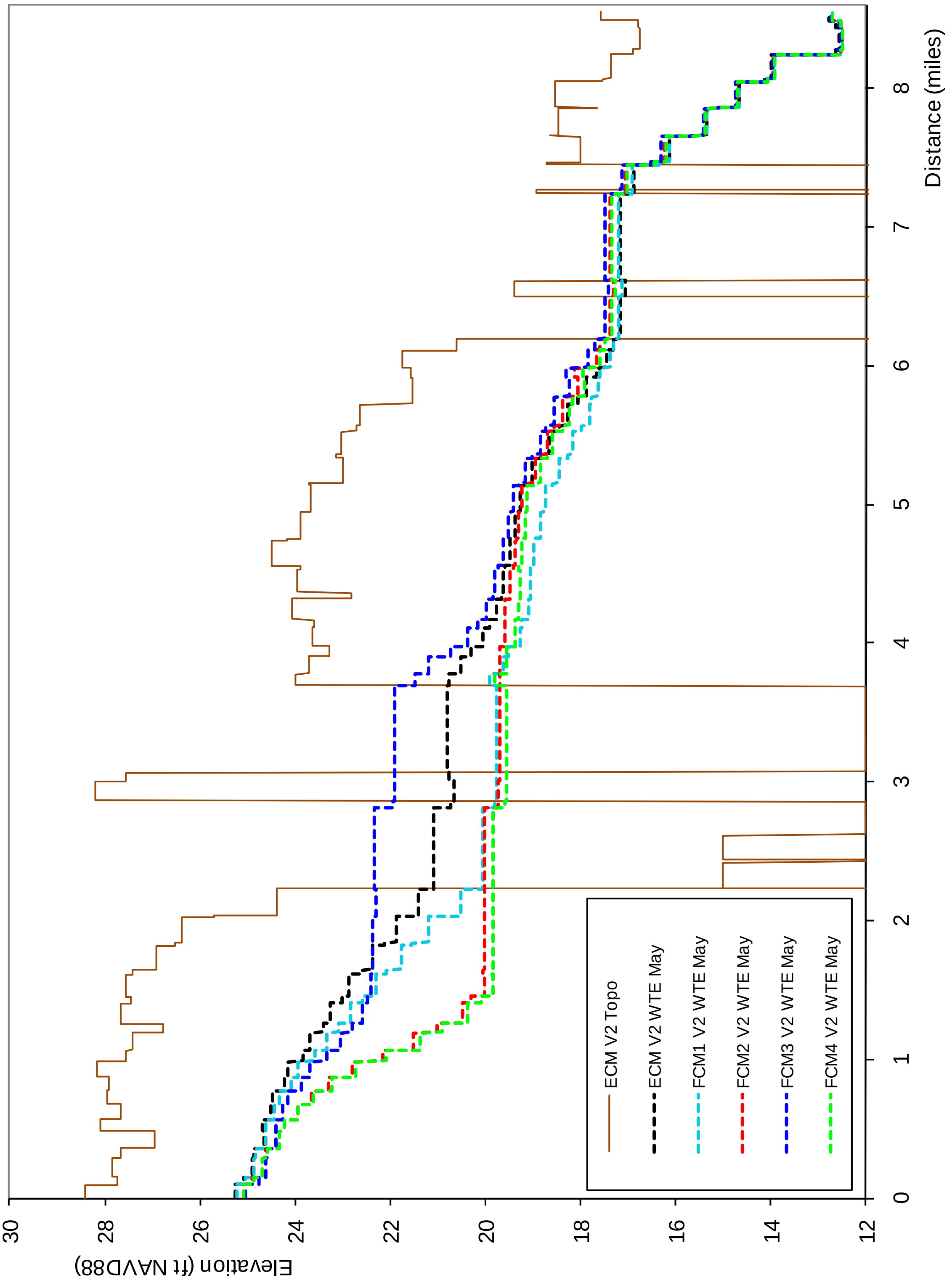

Figure 80. Water table level profile along Transect 1 presented in **Figure 30** at the end of the dry season.

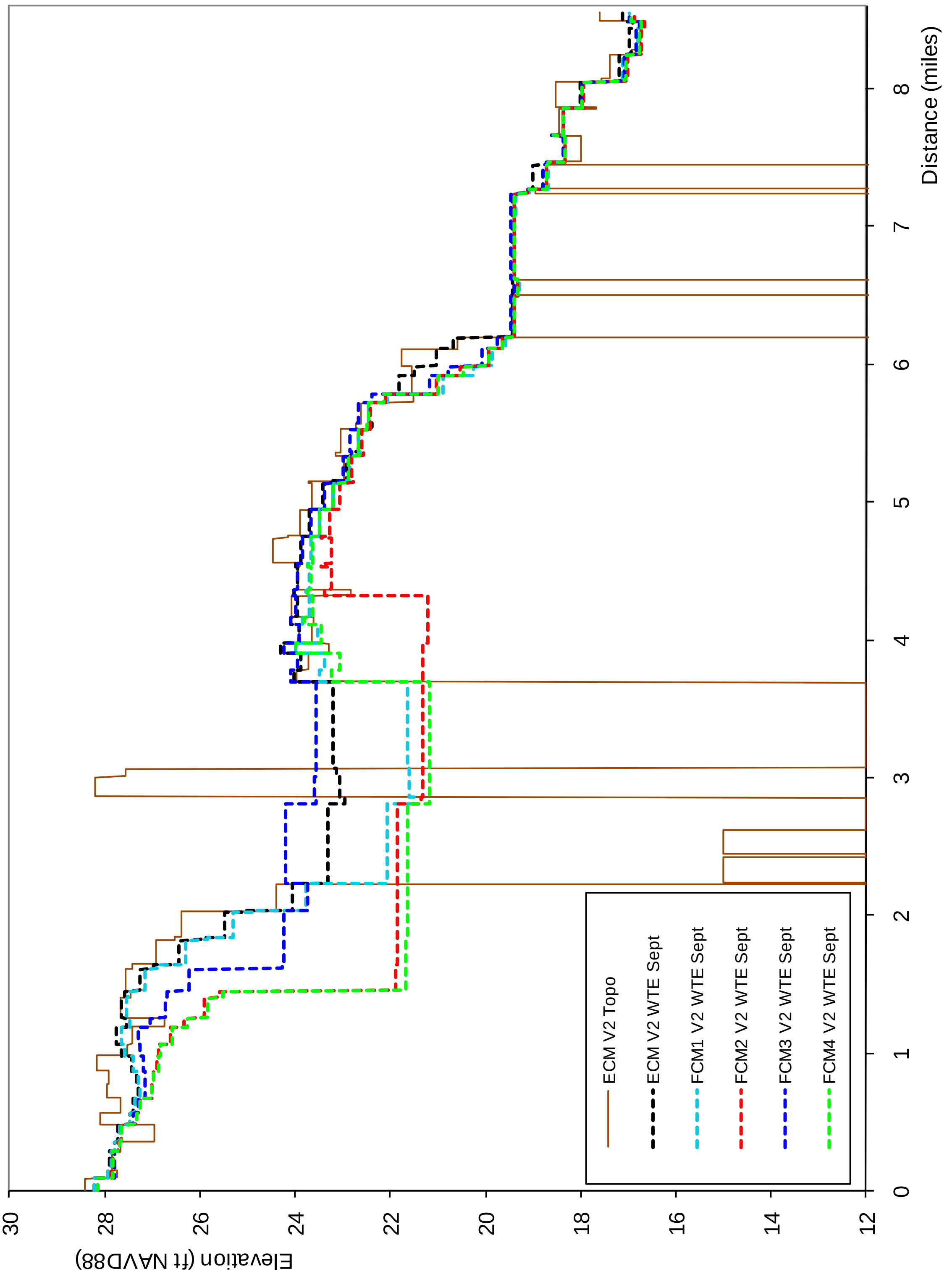

Figure 81. Water table level profile along Transect 1 presented in Figure 30 at the end of the wet season.

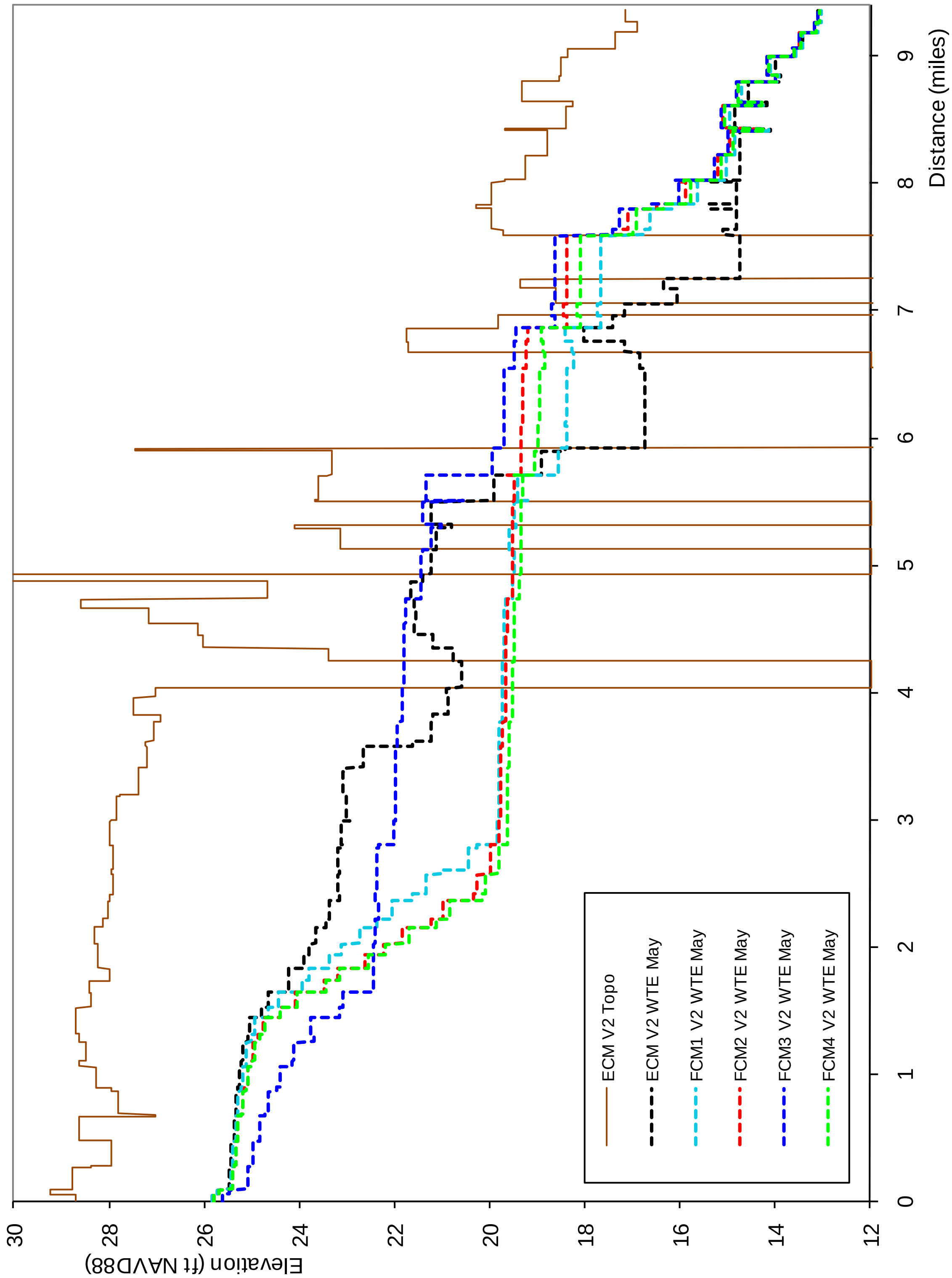

Figure 82. Water table level profile along Transect 2 presented in Figure 30 at the end of the dry season.

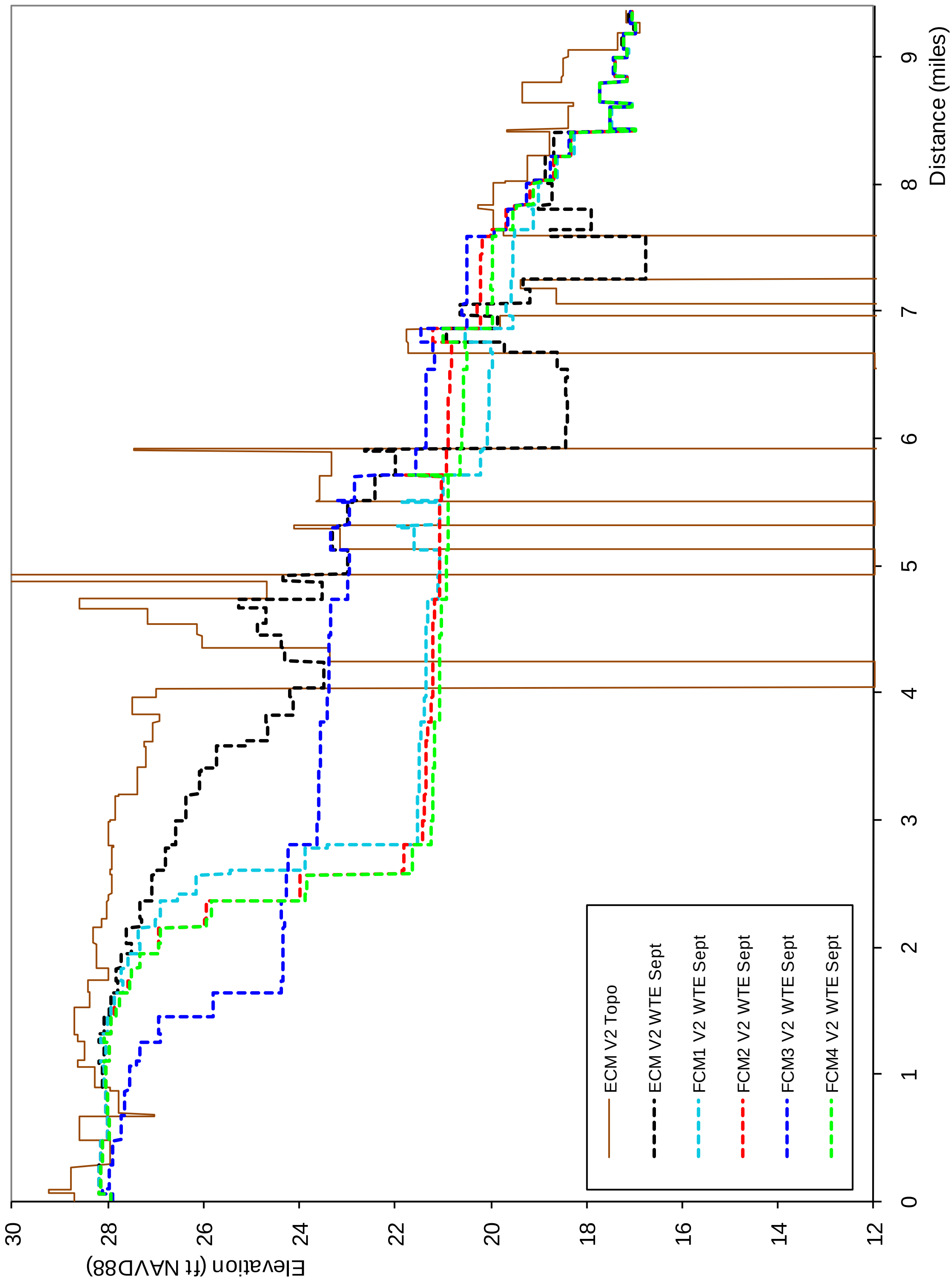

Figure 83. Water table level profile along Transect 2 presented in Figure 30 at the end of the wet season.

Water Table Maps Statistical Analysis

A statistical analysis of the water table difference maps (Figure 72 to Figure 79) was performed by considering grid model cells inside the DR/GR Area that are classified as "natural" land uses (land use codes from 7 to 19). From those grid cells, an average difference was computed. Additionally, the differences were divided into classes matching those shown in the legend of those figures. The number of grid cells that were wetter (positive differences) minus the number of drier grid cells (negative differences) was calculated. The result of this processing is shown in **Table 14**.

The DR/GR Area has been dried out through the years with respect to the predevelopment (natural system) conditions. Thus, it is desirable to increase the water table levels in natural areas inside the DR/GR Area. Consequently, a higher average difference in water table levels (corresponding to wetter conditions at those locations) may be considered a desirable net impact and lower average water table levels could be considered as a negative impact. A higher number of wetter minus drier cells may also be an indication of a desirable net impact. In the former case, the impact is referred to as a net water level change, and in the second case as a net areal extent of wetter conditions. Usually, a net positive impact from a FCM is shown in both water level and areal extent.

According to this statistical processing for natural areas remaining in the DR/GR Area, the dry-season water table elevation differences are highest in the FCM3 and lowest in the FCM1. In the case of the wet-season water table elevation differences, they are highest in the FCM4 and lowest in the FCM3.

Table 14. Statistical processing of the water table difference maps.

FCM Maps	Statistical parameter	FCM1	FCM2	FCM3	FCM4
Water Table Level differences at the end of the dry season (May)	spatial average (ft)	0.010	0.033	0.178	0.096
	Number of wetter minus drier 750-ft grid cells	-216	16	736	256
Water Table Level differences at the end of the wet season (September)	spatial average (ft)	-0.037	-0.030	-0.054	0.012
	Number of wetter minus drier 750-ft grid cells	82	48	6	372

Hydroperiod Maps

Hydroperiod maps obtained from all the FCMs are presented in Appendix H. **Figure 84** through **Figure 87** illustrate the hydroperiod differences between the various scenarios and the existing conditions model (ECM) inside the DR/GR Area. Those maps are a complementary indicator to measure the impact of the land use changes on natural wetland areas.

The hydroperiod results are consistent with water table results previously displayed. The areas that show hydroperiod differences in the Future Condition Models (FCMs) in general correspond to the areas that show differences in water table elevations at the end of the wet season.

Increasing the areal coverage of mining pits in the large mining pit complex of the DR/GR Area causes differences in the hydroperiod in surrounding areas. In general, the hydroperiod decreases with decreased water table levels up gradient of the mining pits and increases with increased water table levels down gradient of the mining pits. The flow ways north of Corkscrew Road experienced the largest negative effect on hydroperiod in the case of the FCM3.

In general, the hydroperiod increases in restored areas (converted from agricultural to wetland). This is a consequence of removing the drainage system of the agricultural area, which tends to lower the water table during the wet season.

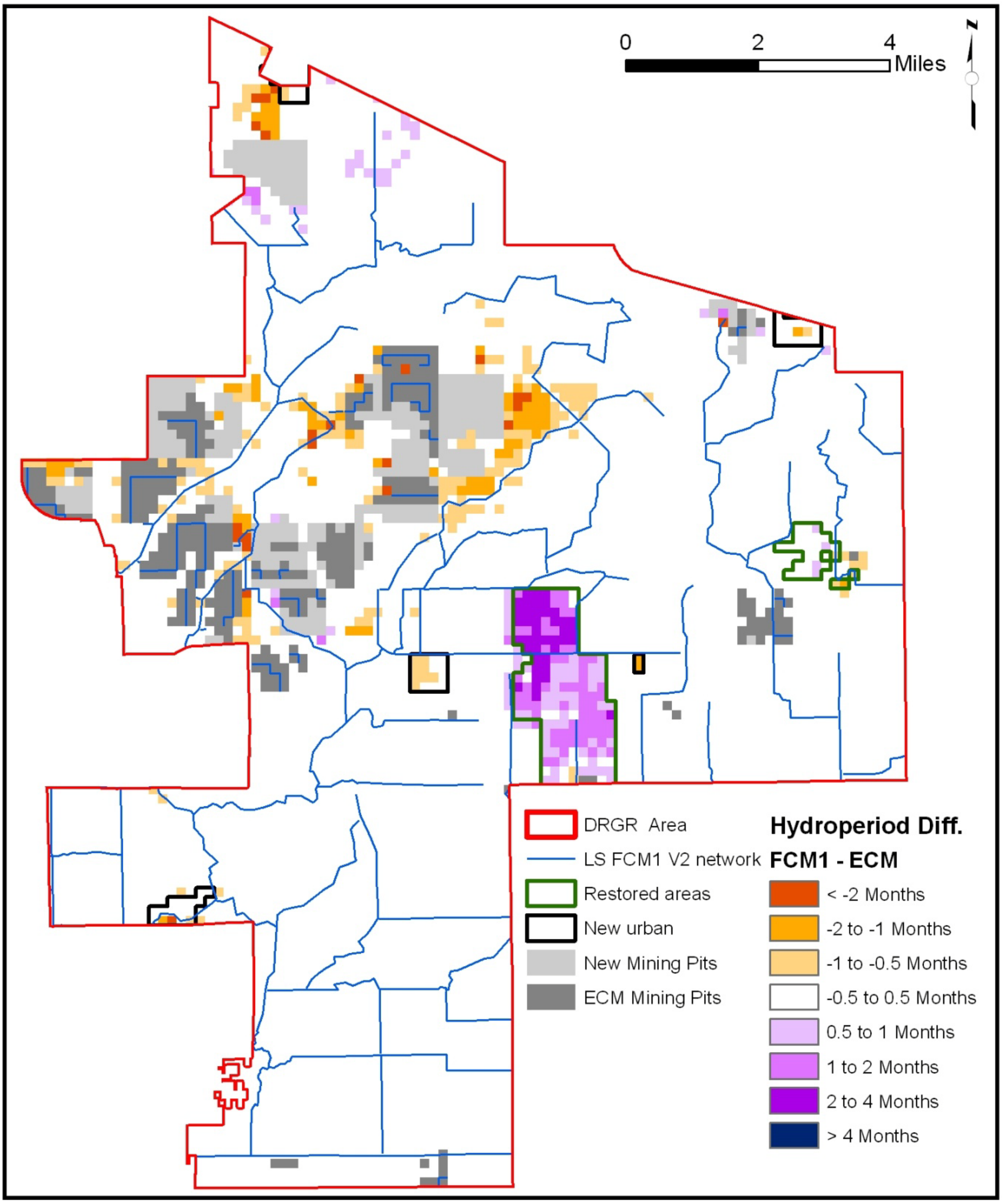

Figure 84. Difference in hydroperiod in FCM1 in relation to the LS ECM (Positive values indicate greater duration of water ponding in FCM1).

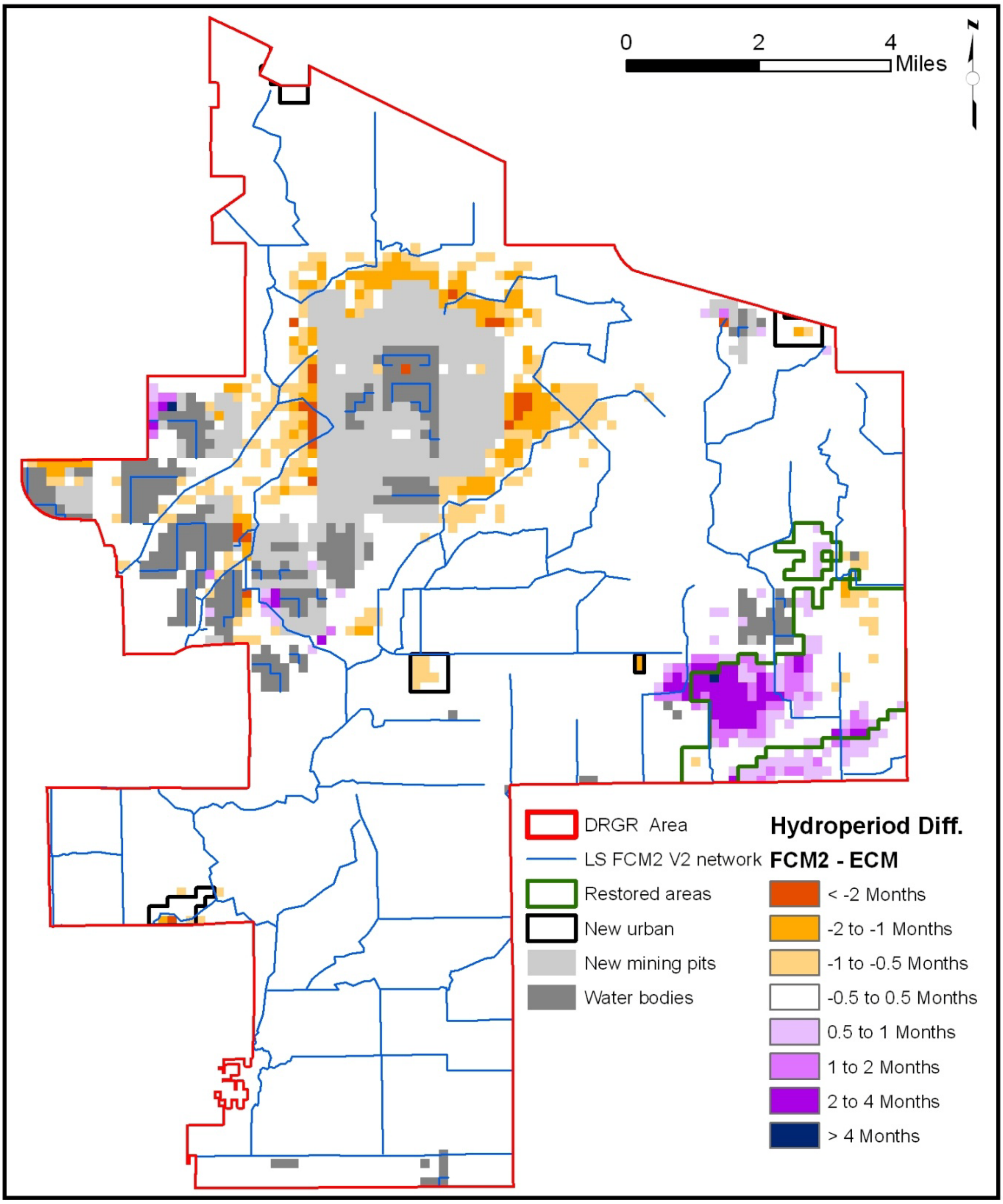

Figure 85. Difference in hydroperiod in FCM2 in relation to the LS ECM (Positive values indicate greater duration of water ponding in FCM2).

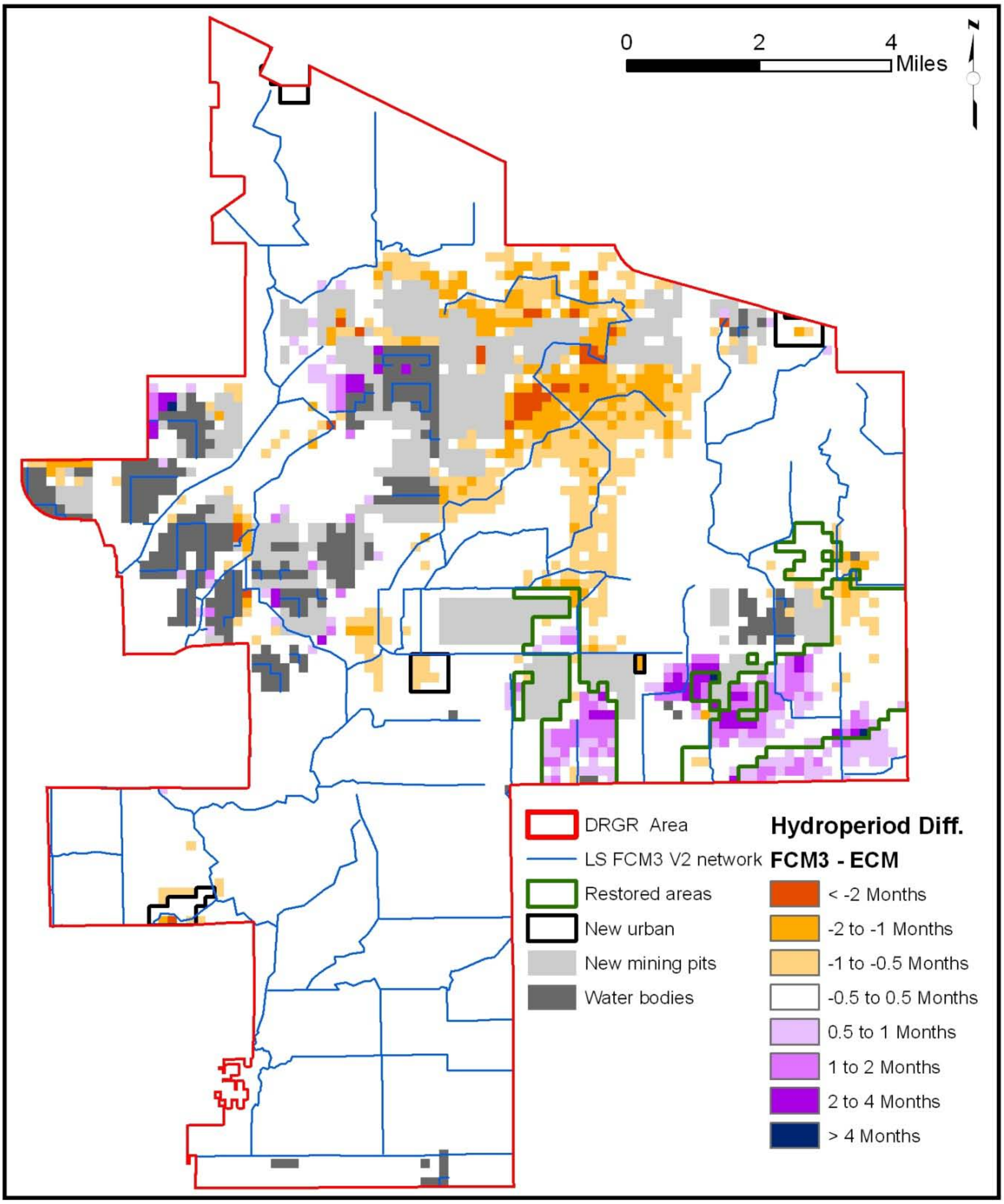

Figure 86. Difference in hydroperiod in FCM3 in relation to the LS ECM (Positive values indicate greater duration of water ponding in FCM3).

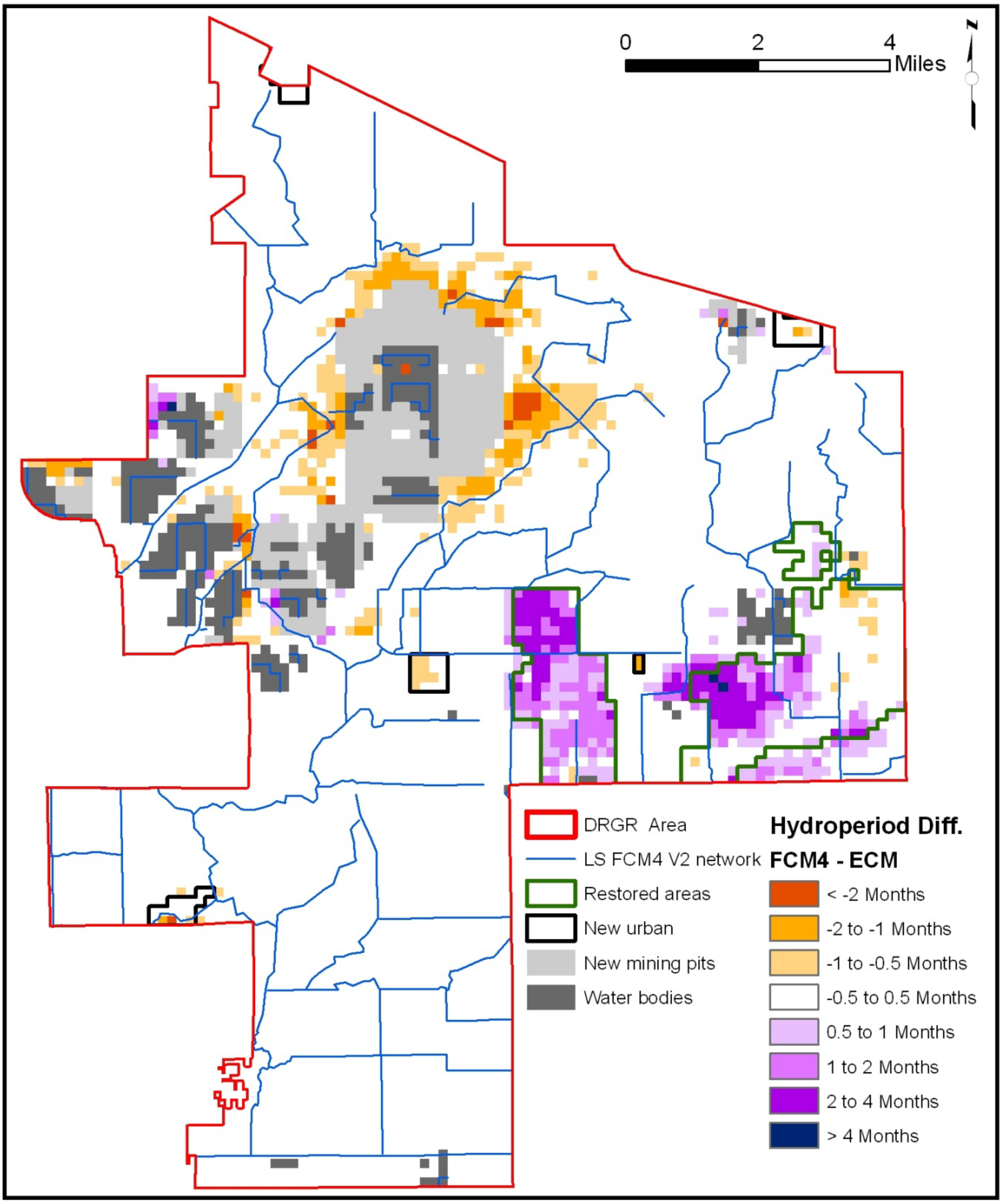

Figure 87. Difference in hydroperiod in FCM4 in relation to the LS ECM (Positive values indicate greater duration of water ponding in FCM4).

Hydroperiod Maps Statistical Analysis

A statistical analysis of the hydroperiod difference maps (Figure 84 to Figure 87) as well as the water depth differences during the hydroperiod (included in Appendix H) was performed by considering grid model cells inside the DR/GR Area that are classified as "natural" land uses (land use codes from 7 to 19). From those grid cells, an average difference was computed. Additionally, the differences were divided into classes matching those shown in the legend of those figures. The number of grid cells that were wetter (positive differences) minus the number of drier grid cells (negative differences) was calculated. The result of this processing is shown in **Table 15**.

An average positive difference in hydroperiod and water depth during the hydroperiod (corresponding to wetter conditions at those locations) may be considered a desirable net impact. A negative average hydroperiod and water depth difference during the hydroperiod could be considered as a negative impact. A higher number of wetter minus drier cells may also be an indication of a desirable net impact. In the former case, the impact is referred to as a net hydroperiod or water depth change, and in the second case as a net areal extent of wetter conditions. Usually, a net positive impact from a FCM is shown in both water level and areal extent.

According to this statistical processing for natural areas remaining in the DR/GR Area, the hydroperiod differences and the water depth differences during the hydroperiod are highest in the FCM4 and lowest in the FCM3.

Table 15. Statistical processing of the hydroperiod difference maps.

FCM Maps	Statistical parameter	FCM1	FCM2	FCM3	FCM4
Hydroperiod differences	spatial average (month)	-0.05	-0.07	-0.11	0.01
	Number of wetter minus drier 750-ft grid cells	-72	-214	-446	160
Water depth differences during hydroperiod	spatial average (in)	-0.08	-0.07	-0.26	0.00
	Number of wetter minus drier 750-ft grid cells	166	136	-614	352

Historic hydroperiod comparison

A natural systems model (NSM) was constructed using the intermediate ECM. This model was intended to be used to help determine future scenarios that most closely returned areas of the DR/GR to their natural states. However, the revised topography changed the hydroperiod prediction significantly and the NSM based on that intermediate step was not accurate enough to be useful for such analyses.

In lieu of the NSM evaluation, a comparison of the hydroperiod maps based on KLECE data for existing conditions (Figure 35) and for the historic conditions (**Figure 88**) was conducted. For the comparison, the hydroperiod (in the mean of the class interval) from those polygon shape file maps was discretized to 750-ft resolution raster maps.

The map with the difference between the existing and the historical mean hydroperiods is shown in **Figure 89**. From that, a map showing the areas where the hydroperiod was increased or decreased was also obtained as shown in **Figure 90**. The area where the hydroperiod has been decreased from the historical conditions is larger, which indicates the DR/GR Area is drier today than it was in the past.

Unfortunately, a direct comparison between the KLECE data (Figure 89) and the modeled maps (Figure 84 to Figure 87) is not possible since the hydroperiod magnitudes reported by KLECE do not correspond exactly to the hydroperiod magnitudes obtained from the model, as discussed in previous sections.

In order to have a semi-quantitative estimation of how close the FCM hydroperiods are with respect to the historical conditions, the following statistical analysis was conducted. FCM hydroperiod difference maps (Figure 84 to Figure 87) were grouped in three classes as was done in Figure 90, i.e., increased (greater than 0.5 months), decreased (lower than negative 0.5 months) and unchanged (otherwise). Then, the grouped FCM hydroperiod differences in natural area (land use codes from 7 to 19) grid cells in the DR/GR Area were compared with the differences in Figure 89. The results are summarized in **Table 16**.

Table 16. Statistical processing of the model- and KLECE-based hydroperiod-grouped-difference maps.

(1) Existing – historical (based on KLECE)	(2) FCM – ECM (based on modeling)	(3) FCM – historical (combined)	(4) FCM direction with respect to historical	(5) Number of natural 750-ft grid cells in the DR/GR Area			
				FCM1	FCM2	FCM3	FCM4
increased	decreased	undefined	neutral	39	37	70	39
increased	unchanged	increased	neutral	412	410	367	404
increased	increased	increased	neutral	35	30	46	64
unchanged	decreased	decreased	negative	91	138	223	118
unchanged	unchanged	unchanged	neutral	1355	1289	1204	1319
unchanged	increased	increased	neutral	53	63	85	100
decreased	decreased	decreased	negative	96	150	217	146
decreased	unchanged	decreased	neutral/negative(*)	1478	1498	1477	1534
decreased	increased	undefined	positive	101	124	153	215
	Positive- minus negative-direction grid cells		case (*) as neutral	-86	-164	-287	-49
			case (*) as negative	-1564	-1662	-1764	-1583

Table 16 shows the combined hydroperiod difference between future and historical conditions also classified as increased, unchanged and decreased. A class labeled as undefined was added to account for areas with the combination of decreased plus increased where the net result of this combination is unknown.

This table also includes a column to classify the direction of changes in future conditions hydroperiod with respect to the historical conditions (see column (4)). Changes are considered to be in the “negative” direction when the FCM predicts the hydroperiod decreases with respect to the ECM and the existing hydroperiod from KLECE decreases or does not change with respect to the historical. It may be considered to be “neutral” or “negative”, when the FCM predicts no changes in hydroperiod with respect to the ECM and the existing hydroperiod from KLECE decreases with respect to the historical. A change is considered to be in the “positive” direction in this column, when the FCM predicts a hydroperiod increase with respect to the ECM and the existing hydroperiod from KLECE decreases with respect to the historical. Other combinations labeled as “neutral” are assumed to produce no changes in that direction. Even when an increase in the future condition hydroperiod with respect to the ECM may be an indication of some mitigation effort, it is not considered as “positive” in the direction toward the historical conditions, if this occurs in a cell that has the same or higher hydroperiod in the existing conditions with respect to the historical conditions, i.e., increasing the period of the ponded water in an area that already has the historical hydroperiod is not considered “positive”.

An overall measure of the direction of the hydroperiod changes with respect to the historical conditions is computed in the last row of Table 16 by subtracting the number of cells with hydroperiod changes in the “negative” direction (in the “FCM direction with respect to historical” column) to the ones in the “positive” direction (in that same column). Two choices are shown by considering the combination “decreased” in column (1) and “unchanged” in column (2) as “neutral” or “negative”. As a result, FCM3 is the scenario with the highest areal extent where the hydroperiod is shorter than in the historical conditions (i.e. it has the most negative number). FCM1 and FCM4 have the lowest areal extent where the hydroperiod is shorter than in the historical conditions (i.e. their results are closest to positive values in the last row of the table).

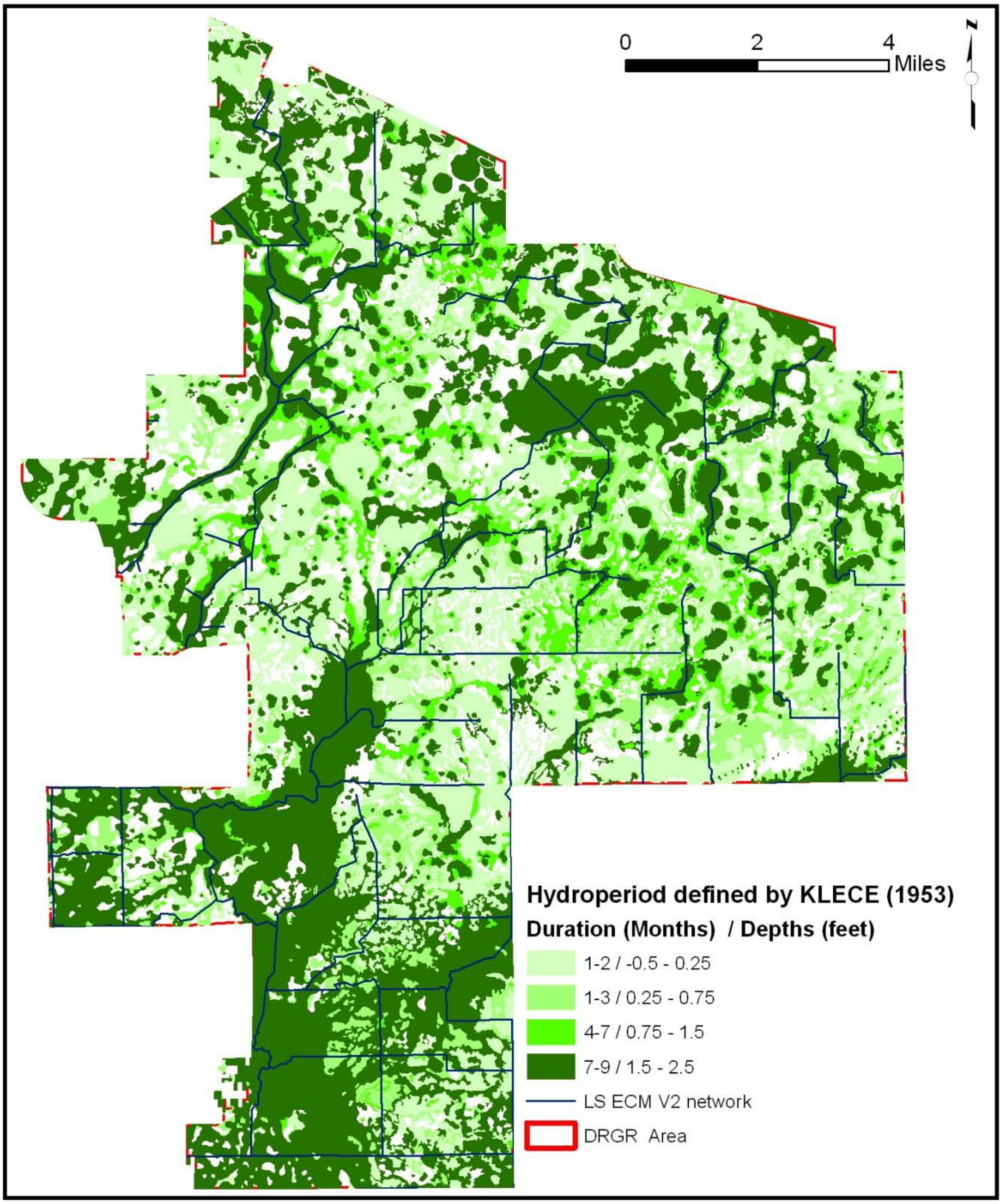

Figure 88. Hydroperiod map generated based on data created by KLECE from 1953 aerial photos.

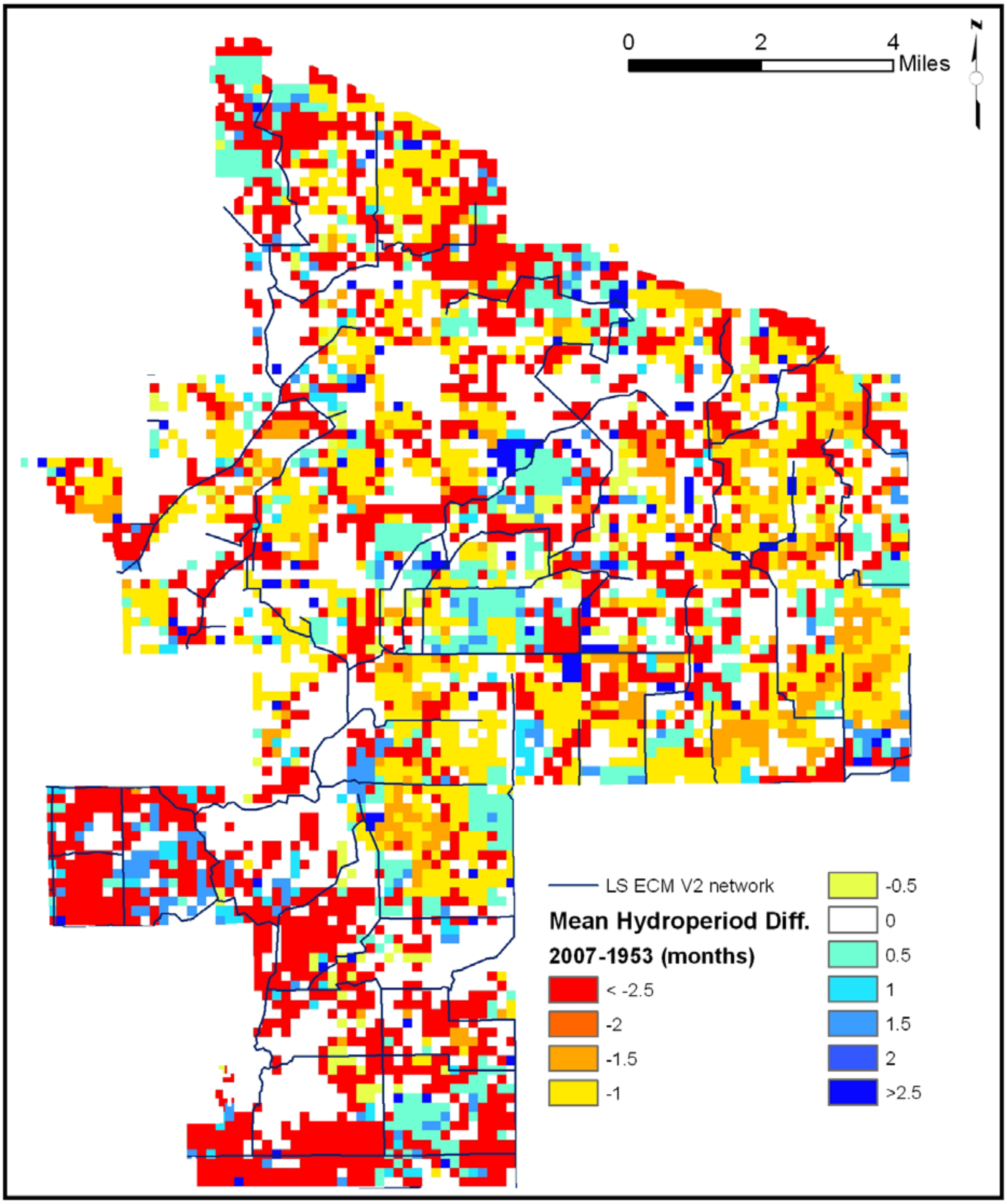

Figure 89. Mean hydroperiod map differences (existing minus historical) based on data created by KLECE from aerial photos.

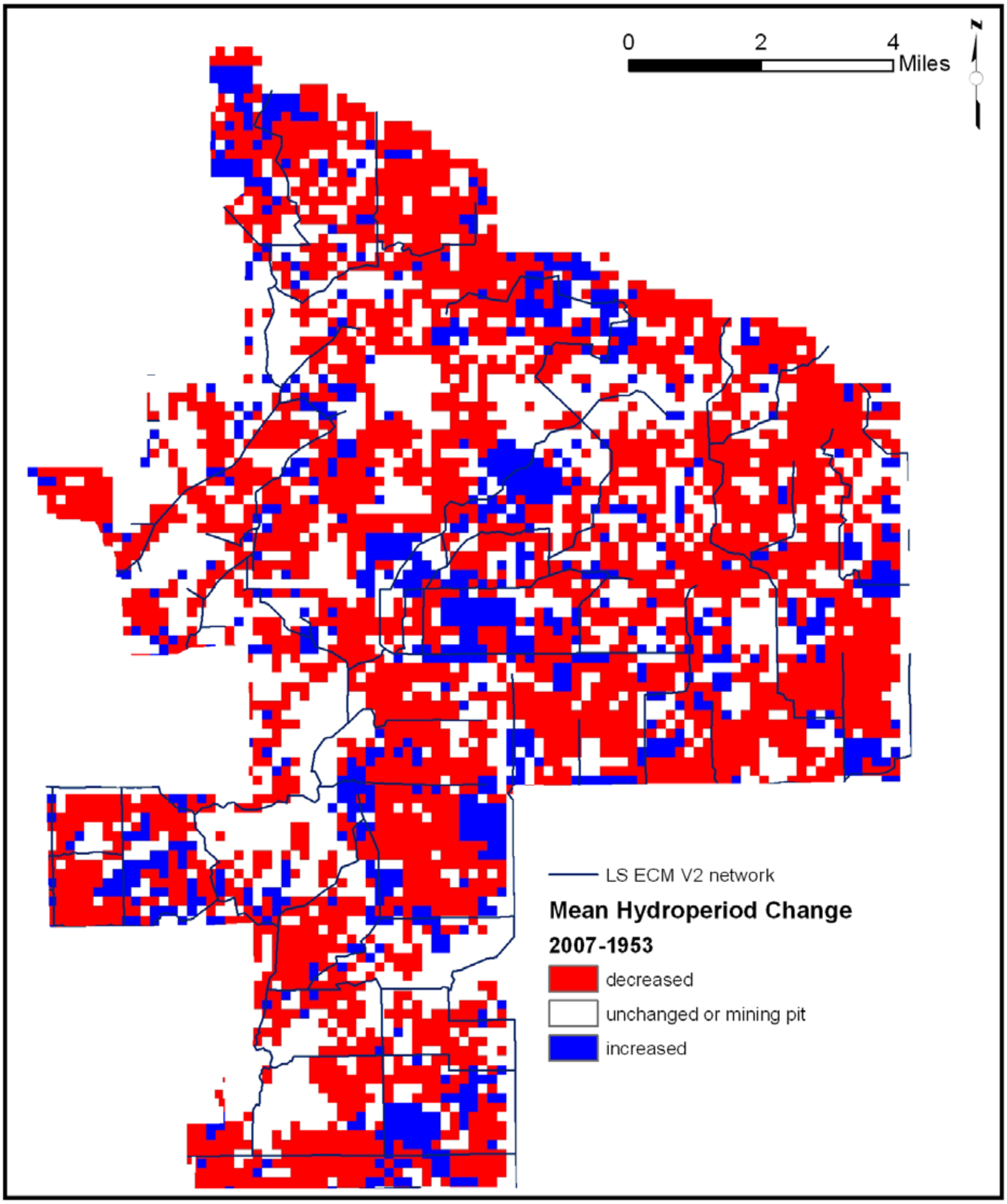

Figure 90. Map of hydroperiod changes after processing the data created by KLECE from aerial photos.

Water Budgets

Water budget calculations conducted for different areas of the models are presented in the following subsections.

DR/GR Area

A detailed water budget component breakdown for the DR/GR Area is presented in **Table 17**, which are annually averaged for all scenarios. More detailed charts for all the scenarios are included in Appendix I. Some of the main components are plotted as a function of the mining pit areal extent in the DR/GR Area and as a function of the area containing mining pits and natural land use in **Figure 91**. A red line is superimposed to highlight the trend of those depth rates with respect to the mining pit area and the mining pit plus natural areas.

The results from the LS ECM and the FCMs indicate, in general, that increased coverage of mining pits and natural areas in a scenario leads to higher evapotranspiration (ET) rates and, therefore, to lower net rainfall (i.e., rainfall - ET) rates. In other words, higher ET rates are found in scenarios where there is a larger area of water ponded or close to the ground surface (i.e., area of mining pits and wetlands).

The annual-averaged surface water outflow (runoff) rates from the DR/GR Area were about 1.1 inch/year lower for the future scenarios with respect to the LS ECM. The correlation in this case with the mining pit areal extents and with the area containing mining pits and natural land use is not as clear in the plot as in the case of the ET. Decreased runoff when more mining pits are present is expected from the higher open-water storage in mining pits and the subsequent absence of runoff from them. A linear extrapolation of the surface water outflow rates in Figure 91 reaches a value of zero at about 45 % areal extent of mining pit coverage. This may be an indication that the mining pits also reduce the surface water flow in neighboring areas and interrupt pre-developed flow ways.

There is a higher pumping rate assumed in the FCMs of about 0.4 inches/year for the entire DRGR area with respect to the LS ECM. This is about one third of the reduction in the SW outflow rate and may be partially contributing to the SW outflow reduction.

The groundwater outflow from the DR/GR Area (labeled as CSZ in Table 17) is an indicator of groundwater recharge in the DR/GR Area. The model results generally show slightly higher groundwater outflow rates from the DR/GR (about 0.2 inches/year) for the future scenarios with respect to the LS ECM. The correlation in this case with the mining pit areal extents and with the area containing mining pits and natural land use is not as clear in the plot as in the case of the ET.

Table 17. Annual average depth rates of the water balance components for the entire DR/GR Area as predicted from different models.

Depth rates (inches/year)	Model	ECM	FCM1	FCM2	FCM3	FCM4
Rainfall		58.88	58.88	58.88	58.88	58.88
ET		48.02	48.53	48.66	48.74	48.48
Rainfall - ET (A)		**10.86**	**10.35**	**10.22**	**10.14**	**10.40**
OL storage change		-0.03	-0.03	0.01	-0.11	0.02
UZ Storage change		0.04	0.04	0.04	0.03	0.04
Total SZ Storage change (BSZ)		-0.38	-0.37	-0.36	-0.34	-0.36
Total storage (B)		**-0.37**	**-0.36**	**-0.31**	**-0.42**	**-0.31**
Net OL Boundary outflow (COL)		0.19	0.17	0.16	0.18	0.21
Drain to Boundary (CDR)		0.00	0.00	0.00	0.00	0.00
Net SZ Boundary outflow from SZ1		1.74	2.00	1.80	1.75	1.81
Net SZ Boundary outflow from SZ2		0.06	0.09	0.08	0.11	0.11
Net SZ Boundary outflow from SZ3		-0.54	-0.59	-0.46	-0.43	-0.46
Net SZ Boundary outflow from SZ4		-0.38	-0.41	-0.36	-0.34	-0.35
Net SZ Boundary outflow from all SZ (CSZ)		0.87	1.10	1.06	1.09	1.11
Total Boundary outflow (C)		**1.06**	**1.26**	**1.22**	**1.26**	**1.32**
Pumping from SZ1		1.18	0.99	0.86	0.68	0.75
Pumping from SZ2		1.02	0.81	0.85	0.73	0.75
Pumping from SZ3		3.09	3.31	2.96	2.89	2.92
Pumping from SZ4		0.50	0.57	0.57	0.56	0.57
Pumping from all SZ		5.79	5.67	5.25	4.87	4.99
Irrigation		2.54	2.09	1.67	1.28	1.41
Pumping-Irrigation (D)		**3.25**	**3.58**	**3.58**	**3.59**	**3.58**
Infiltration from OL to SZ1		27.86	24.16	22.41	19.71	22.42
Infiltration from SZ1 to SZ2		3.70	3.74	3.60	3.48	3.50
Infiltration from SZ2 to SZ3		2.63	2.84	2.69	2.65	2.65
Infiltration from SZ3 to SZ4		0.11	0.14	0.20	0.21	0.21
OL->river		-14.66	-11.90	-10.73	-8.38	-10.87
Drain to river		21.62	17.64	16.42	14.01	16.63
Drain to ext. river		0.21	0.30	0.20	0.22	0.21
Base flow to River		-0.25	-0.18	-0.16	-0.13	-0.16
Total flow to river (E)		**6.92**	**5.86**	**5.73**	**5.71**	**5.81**
Error (A-B-C-D-E)		0.01	0.00	0.00	0.01	0.01
Boundary surface outflow (runoff)	COL+CDR+E	7.11	6.03	5.89	5.88	6.02
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Net groundwater recharge	A-(B-BSZ)-(C-CSZ)-E= BSZ+CSZ+D	3.73	4.30	4.27	4.33	4.33
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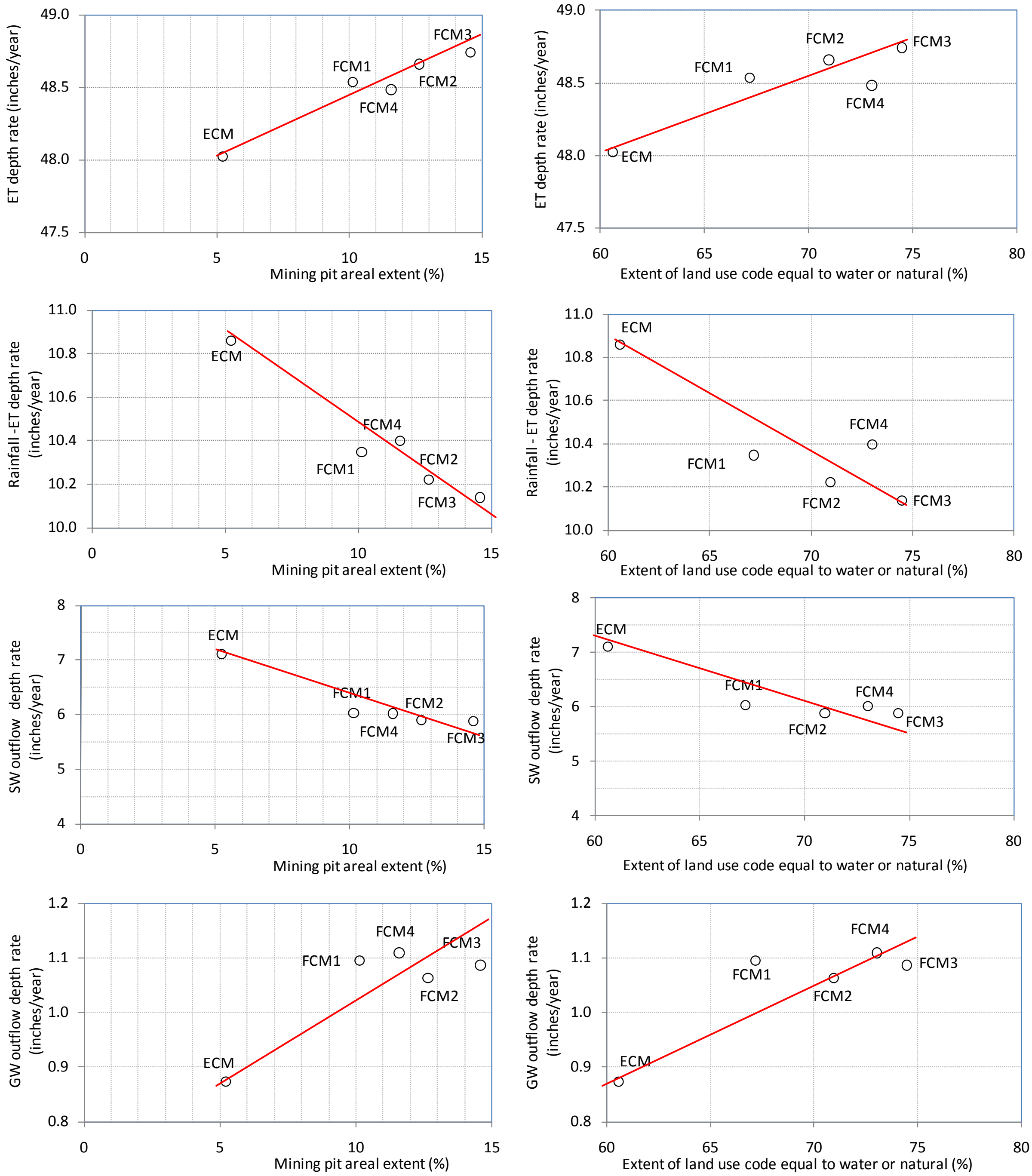

Figure 91. Annual averaged Water Balance Components in the DR/GR Area from all Models.

The seasonal oscillation of the main water balance components is shown in **Figure 92** through **Figure 95**. Daily ET rates are higher from April to September due to the higher temperatures. The daily net rainfall rate is positive from mid May to mid October (rainy season), which approximately matches the period of positive surface water outflow from the DR/GR Area. The surface water outflow rate peaks during the months of August and September (late wet season). Groundwater outflows are higher from August to November.

Different land use scenarios show slight differences in seasonal patterns, which cause the differences in the annual averaged values presented in Table 17. ET and groundwater outflow rate differences are lower in the wet months and higher in drier months. Conversely, surface water outflow rate differences are lower in drier months and higher in wet months.

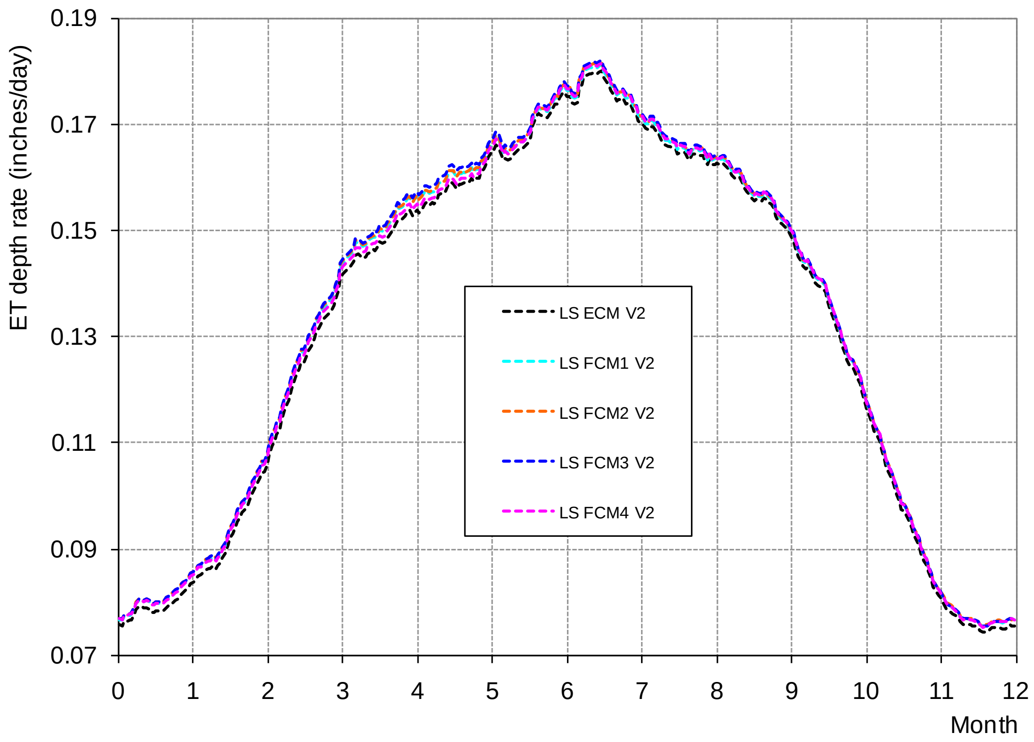

Figure 92. Seasonal averaged evapotranspiration in the DR/GR Area for all scenarios.

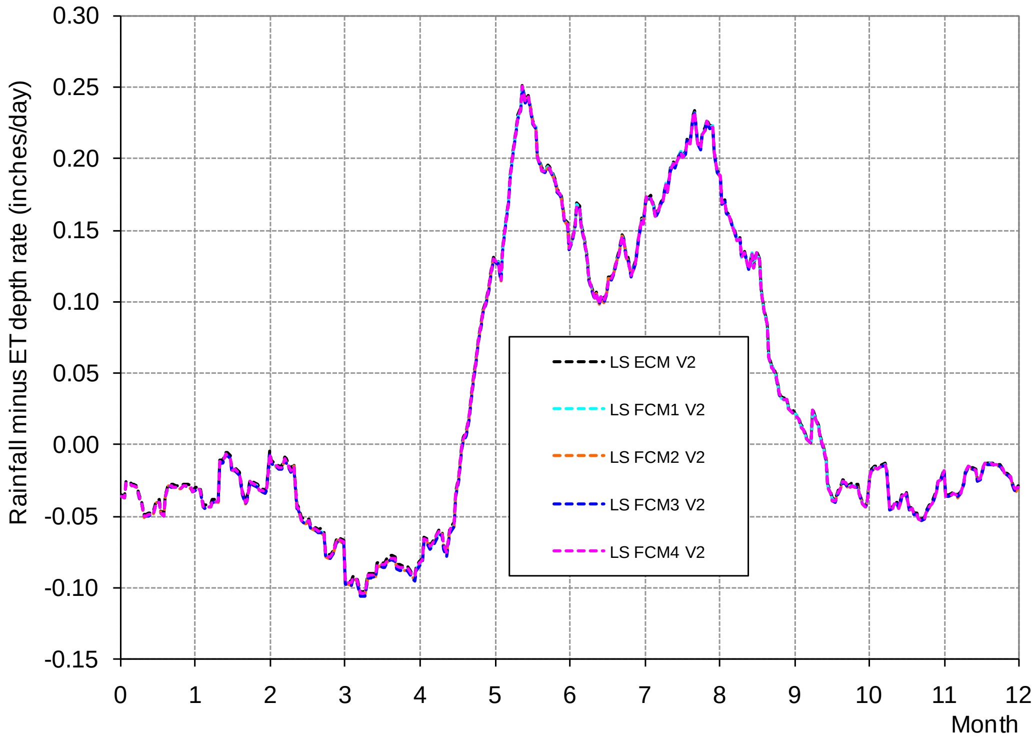

Figure 93. Seasonal averaged net rainfall in the DR/GR Area for all scenarios.

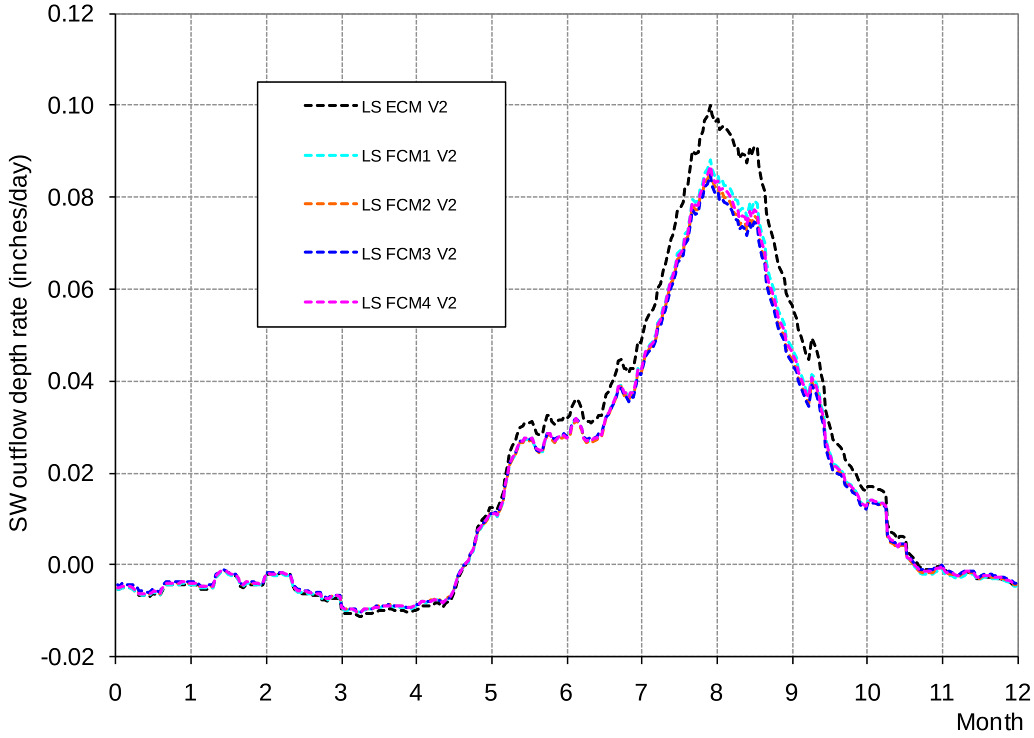

Figure 94. Seasonal surface water outflow from the DR/GR Area for all scenarios.

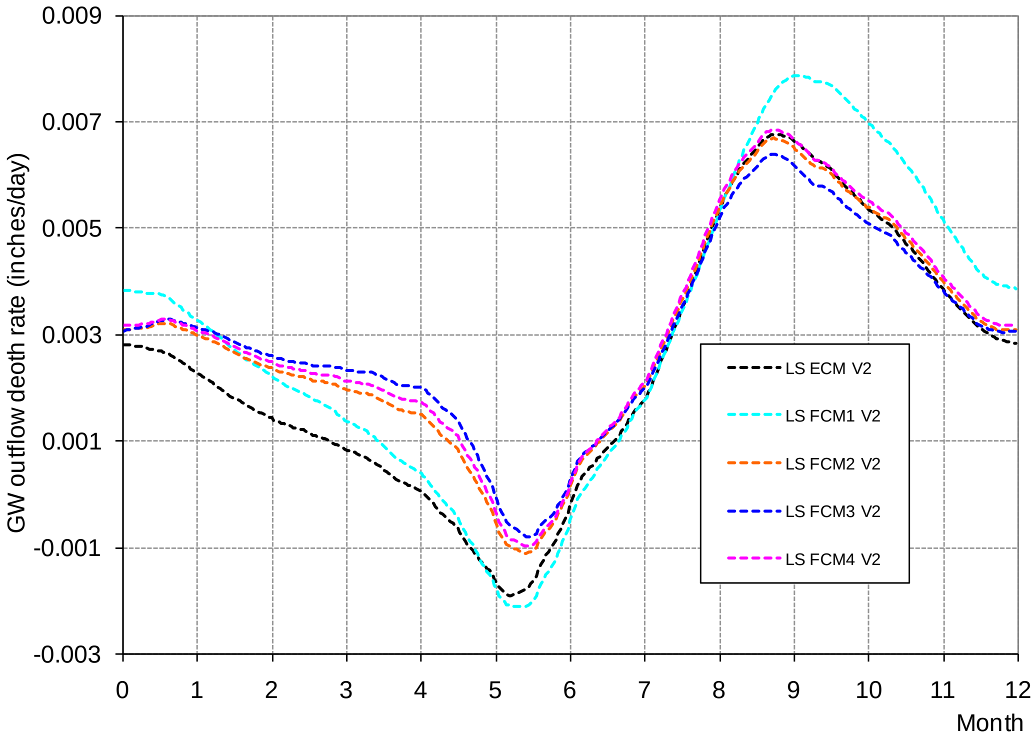

Figure 95. Seasonal groundwater outflow from the DR/GR Area for all scenarios.

Mining Pits and Lakes

A detailed water budget component breakdown for mining pits and shallow water bodies around the DR/GR area is presented in **Table 18**. Notice that the average ET depth rate in the water bodies does not differ significantly from the one in the ECM. Thus, the ET volumetric rate is approximately proportional to the area covered by the water bodies, and this supports the linear correlation between the ET depth rate for the entire DR/GR and the mining pit areal coverage shown previously in Figure 91.

As previously observed when discussing the ECM results in Table 8, the net rainfall (rainfall minus ET) in mining pits and lakes is approximately zero inches per year. Moreover, a positive outflow from the drainage system around mining pits is predicted from the model. As a result, the aquifers need to supply water to the mining pits (negative net groundwater recharge) approximately equal to the amount that is lost through the drainage system (3.8 to 7.0 inches/year).

Observation data, other than the LIDAR, for modeling the drainage system around the mining pits was not available, and there may be inaccuracies. However, if these outflows from mines are verified in the field, the construction of flow barriers (berms, flow structures, etc.) in those locations may reduce the outflow (negative recharge) from the aquifers.

Table 18. Annual average depth rates of the water balance components for mining pits and lakes around the DR/GR area as predicted from different models.

Depth rates (inches/year)	Model	ECM	FCM1	FCM2	FCM3	FCM4
Rainfall		59.10	59.59	59.23	58.81	59.00
ET		59.09	59.14	59.04	58.98	59.02
Rainfall - ET (A)		0.00	0.46	0.19	-0.17	-0.02
OL storage change		-0.13	-0.15	0.21	-0.54	0.24
UZ Storage change		0.00	0.00	0.00	0.00	0.00
Total SZ Storage change (BSZ)		-0.02	-0.02	-0.01	-0.03	-0.01
Total storage (B)		-0.15	-0.17	0.19	-0.57	0.23
Net OL Boundary outflow (COL)		0.03	0.01	0.01	0.17	0.01
Drain to Boundary (CDR)		0.00	0.00	0.00	0.00	0.00
Net SZ Boundary outflow from SZ1		-9.02	-10.89	-9.75	-8.10	-10.18
Net SZ Boundary outflow from SZ2		-2.08	-0.49	-0.57	-0.17	-0.66
Net SZ Boundary outflow from SZ3		2.79	3.45	3.68	2.99	3.64
Net SZ Boundary outflow from SZ4		0.10	0.41	0.74	0.35	0.63
Net SZ Boundary outflow from all SZ (CSZ)		-8.20	-7.51	-5.91	-4.94	-6.57
Total Boundary outflow (C)		-8.17	-7.50	-5.90	-4.77	-6.56
Pumping from SZ1		0.48	0.01	0.00	0.01	0.00
Pumping from SZ2		2.33	0.67	0.83	0.74	0.90
Pumping from SZ3		0.18	0.12	0.17	0.15	0.18
Pumping from SZ4		0.56	0.36	0.48	0.42	0.52
Pumping from all SZ		3.55	1.16	1.49	1.32	1.60
Irrigation		0.00	0.00	0.00	0.00	0.00
Pumping-Irrigation (D)		3.55	1.16	1.49	1.32	1.60
Infiltration from OL to SZ1		-4.67	-6.38	-4.44	-3.64	-4.98
Infiltration from SZ1 to SZ2		3.87	4.50	5.31	4.45	5.20
Infiltration from SZ2 to SZ3		3.62	4.32	5.05	3.89	4.96
Infiltration from SZ3 to SZ4		0.65	0.76	1.21	0.76	1.14
OL->river		4.77	6.97	4.41	3.85	4.71
Drain to river		0.00	0.00	0.00	0.00	0.00
Drain to ext. river		0.00	0.00	0.00	0.00	0.00
Base flow to River		0.00	0.00	0.00	0.00	0.00
Total flow to river (E)		4.77	6.97	4.41	3.85	4.71
Error (A-B-C-D-E)		0.00	0.00	0.00	0.00	0.00
Boundary surface outflow (runoff)	---	---	---	---	---	---
	COL+CDR	0.03	0.01	0.01	0.17	0.01
Net groundwater recharge	A-(B-BSZ)-(C-CSZ)-E= BSZ+CSZ+D	-4.67	-6.37	-4.44	-3.64	-4.98
	A= B+C+D+E	0.00	0.45	0.19	-0.17	-0.02

Isolated Mine in FCM1

An isolated mine in a relatively flat area located in the northwest corner of the DR/GR Area was considered in future condition model 1 (FCM1). The water table plot in locations M1, M2, and M3, presented in previous sections, showed that the mine is acting like a groundwater reservoir, i.e., releasing water (collected during the rainy season) into the aquifers during the dry season. This may be a unique characteristic of this mine. All the mines in the other scenarios experience too much influence from surrounding mines to determine whether or not they also act as reservoirs.

A water balance calculation was conducted in the proposed mining pit area from the LS ECM and the FCM1 results. The annual averaged rates from 2002 to 2006 are presented in **Table 19**.

The annual averaged net groundwater recharge from that mining pit presented in Table 19 went from -3.7 inches in the ECM to 7.2 inches in the FCM1. This positive increase in the groundwater recharge, however, is accompanied by an increase in the annual ET depth of 10.4 inches and a decrease in the surface water outflow (runoff) of 20.4 inches. In summary, this new proposed mine would increase the groundwater recharge by retaining the pre-mined runoff, but at the cost of losing about half of it as ET.

A comparison between Table 13 and Table 19 reveals that the average annual rainfall in that mining pit area is about 7.4 inches higher than in the entire DR/GR Area and in the entire mining pits and lakes area. The monthly rainfall time series is compared in **Figure 96** for both areas. It is not clear if that higher rainfall rate is due to local climatic conditions or due to the statistical fluctuations expected when analyzing a smaller area. In any case, that mining pit with an annual rainfall that exceeds RET by 19.6% is not representative of the entire DR/GR area where annual rainfall exceeds RET on average by about 8%.

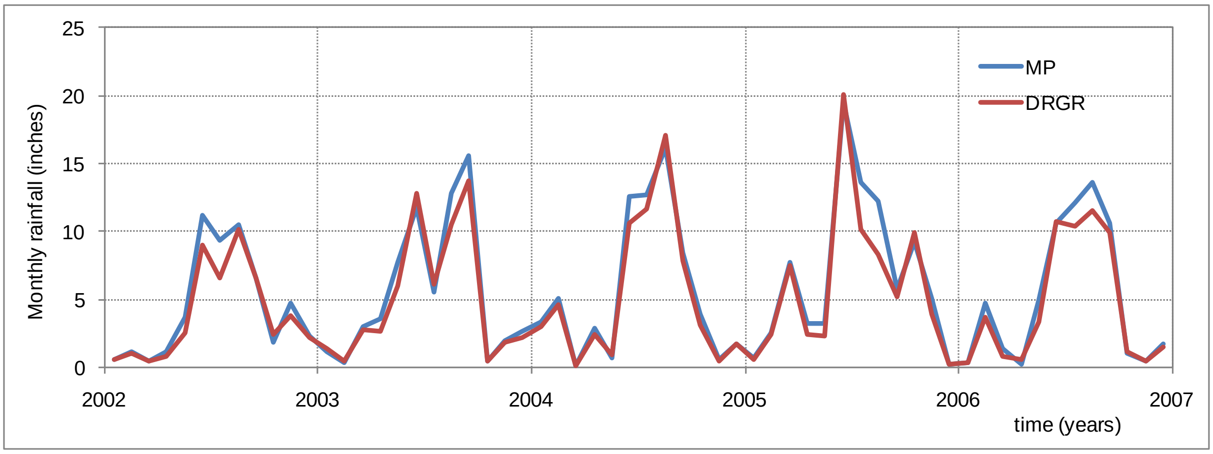

Figure 96. Monthly rainfall in the mining pit area (MP) containing site M2 in Figure 43 compared to the averaged monthly rainfall in the DR/GR Area.

Table 19. Annual average depth rates of the water balance components in a mining pit area located in the northwest corner of the DR/GR Area in the FCM1.

Depth rates (inches/year)	Model	LS ECM	LS FCM1
Rainfall		66.4	66.4
ET		49.8	60.1
Rainfall - ET (A)		**16.7**	**6.3**
OL storage change		0.0	-0.9
UZ Storage change		0.0	0.0
Total SZ Storage change (BSZ)		-0.3	-0.1
Total storage (B)		**-0.3**	**-1.0**
Net OL Boundary outflow (COL)		-9.6	0.0
Drain to Boundary (CDR)		0.0	0.0
Net SZ Boundary outflow from SZ1		-4.5	6.0
Net SZ Boundary outflow from SZ2		0.0	0.0
Net SZ Boundary outflow from SZ3		1.3	1.4
Net SZ Boundary outflow from SZ4		-0.1	-0.1
Net SZ Boundary outflow from all SZ (CSZ)		-3.4	7.3
Total Boundary outflow (C)		**-13.0**	**7.3**
Pumping from SZ1		0.0	0.0
Pumping from SZ2		0.0	0.0
Pumping from SZ3		0.0	0.0
Pumping from SZ4		0.0	0.0
Pumping from all SZ		0.0	0.0
Irrigation		0.0	0.0
Pumping-Irrigation (D)		**0.0**	**0.0**
Infiltration from OL to SZ1		82.2	7.2
Infiltration from SZ1 to SZ2		1.1	1.2
Infiltration from SZ2 to SZ3		1.1	1.2
Infiltration from SZ3 to SZ4		-0.2	-0.2
OL->river		-56.0	0.0
Drain to river		82.2	0.0
Drain to ext. river		4.5	0.0
Base flow to River		-0.8	0.0
Total flow to river (E)		**29.9**	**0.0**
Error (A-B-C-D-E)		0.0	0.0
Boundary surface outflow (runoff)	COL+CDR+E	20.4	0.0
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Net groundwater recharge	A-(B-BSZ)-(C-CSZ)-E= BSZ+CSZ+D	-3.7	7.2
	A= B+C+D+E	---	6.3

New Urban Areas

A water budget calculation was performed in four new urban areas corresponding to the sites labeled from U1 through U4 in Figure 43. The comparison of the annual rates between the ECM and the FCMs are presented in **Table 20**. The differences between the scenarios were small, and just the averaged rate from the four scenarios is displayed.

In general, the modeling predicts that new urban areas have lower ET rates with respect to the existing conditions. This is consistent with the low values of LAI and Rd assumed for this land use classification (see Table 4). Moreover, the absence of irrigation systems assumed in the new urban areas at sites U2 and U4, may contribute to the reduction of the ET losses in those areas. The lower actual ET rate is likely the main reason of why the dry-season water table levels in the new urban areas are in general higher than in the ECM.

Table 20. Annual average depth rates of the water balance components in new urban areas.

Site		U1		U2		U3		U4	
Depth rates (inches/year)	**Model**	**ECM**	**FCMs**	**ECM**	**FCMs**	**ECM**	**FCMs**	**ECM**	**FCMs**
Rainfall		64.6	64.6	57.5	57.5	57.5	57.5	56.2	56.2
ET		46.9	45.8	47.9	41.6	52.5	43.1	52.9	35.9
Rainfall - ET (A)		**17.7**	**18.8**	**9.7**	**16.0**	**5.0**	**14.4**	**3.2**	**20.3**
OL storage change		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UZ Storage change		-0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0
Total SZ Storage change (BSZ)		-0.4	-0.3	-0.2	-0.2	-0.5	-0.6	-0.3	-0.2
Total storage (B)		**-0.4**	**-0.3**	**-0.1**	**-0.1**	**-0.5**	**-0.4**	**-0.3**	**-0.2**
Net OL Boundary outflow (COL)		-2.6	-5.7	-2.9	-28.7	-41.3	-55.5	-0.6	-0.9
Drain to Boundary (CDR)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net SZ Boundary outflow from SZ1		-5.0	-3.6	8.7	-14.1	-24.2	-39.3	-9.0	0.8
Net SZ Boundary outflow from SZ2		0.0	0.0	0.9	-1.6	0.0	0.0	-0.1	-0.1
Net SZ Boundary outflow from SZ3		5.7	-1.6	0.9	0.9	-10.3	-9.5	5.5	8.4
Net SZ Boundary outflow from SZ4		-0.7	-1.0	0.3	0.4	-0.6	-0.5	1.5	1.9
Net SZ Boundary outflow from all SZ (CSZ)		0.0	-6.2	10.8	-14.4	-35.1	-49.2	-2.1	11.1
Total Boundary outflow (C)		**-2.6**	**-11.9**	**7.9**	**-43.1**	**-76.3**	**-104.8**	**-2.7**	**10.2**
Pumping from SZ1		0.0	0.0	0.1	0.0	0.7	0.0	13.5	0.0
Pumping from SZ2		0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Pumping from SZ3		0.4	8.1	0.0	0.0	13.5	12.5	0.0	0.0
Pumping from SZ4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pumping from all SZ		0.4	8.1	0.1	0.0	14.3	12.5	13.5	0.0
Irrigation		0.4	8.1	0.5	0.0	7.1	5.3	13.5	0.0
Pumping-Irrigation (D)		**0.0**	**0.0**	**-0.4**	**0.0**	**7.2**	**7.2**	**0.0**	**0.0**
Infiltration from OL to SZ1		20.8	32.4	100.0	339.5	53.2	75.1	17.2	21.1
Infiltration from SZ1 to SZ2		5.3	5.4	2.1	-0.2	2.6	2.5	6.9	10.2
Infiltration from SZ2 to SZ3		5.3	5.4	1.2	1.3	2.6	2.4	7.0	10.3
Infiltration from SZ3 to SZ4		-0.8	-1.0	0.3	0.4	-0.6	-0.5	1.5	1.9
OL->river		0.0	0.2	-87.0	-294.8	0.0	0.0	0.0	0.0
Drain to river		0.0	0.0	90.1	323.6	0.0	0.0	6.3	10.3
Drain to ext. river		20.7	30.8	0.0	32.0	74.5	112.4	0.0	0.0
Base flow to River		0.0	0.0	-0.8	-1.5	0.0	0.0	-0.1	-0.1
Total flow to river (E)		**20.7**	**31.0**	**2.3**	**59.2**	**74.5**	**112.4**	**6.2**	**10.2**
Error (A-B-C-D-E)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Surface Water Flows

Figure 97 shows a map of locations that were selected for comparison of surface water flow rates among different model scenarios. The annual averaged flow rates presented in **Table 21** show that the flow rate in the main pathways of the DR/GR decreases in the future condition scenarios. This is consistent with the reduction of the total surface outflow rate from the DR/GR Area in the FCMs, as discussed in the previous section.

Table 21. Annual average flow rates at selected pathway locations.

Flow Location	Flow (%)	Flow percentage differences regarding ECM			
	ECM	FCM1	FCM2	FCM3	FCM4
AL	18.6	-4.7	-8.1	-3.9	-6.5
CSa	22.5	-9.7	-10.1	-7.6	-9.6
CSb	3.9	0.0	0.2	-0.6	0.2
CSc	4.9	0.0	-1.8	-2.3	-1.8
CSd	55.0	-7.2	-9.6	-4.5	-7.1
I-75a	35.6	-9.1	-9.3	-10.0	-9.2
I-75b	27.7	-7.3	-6.8	-14.6	-7.8
I-75c	13.3	-2.2	-2.1	-2.7	-2.2
I-75d	100.0	-0.6	-0.8	-2.2	-0.1

Note: A flow of 100 % corresponds to 37.4 ft^3/s.

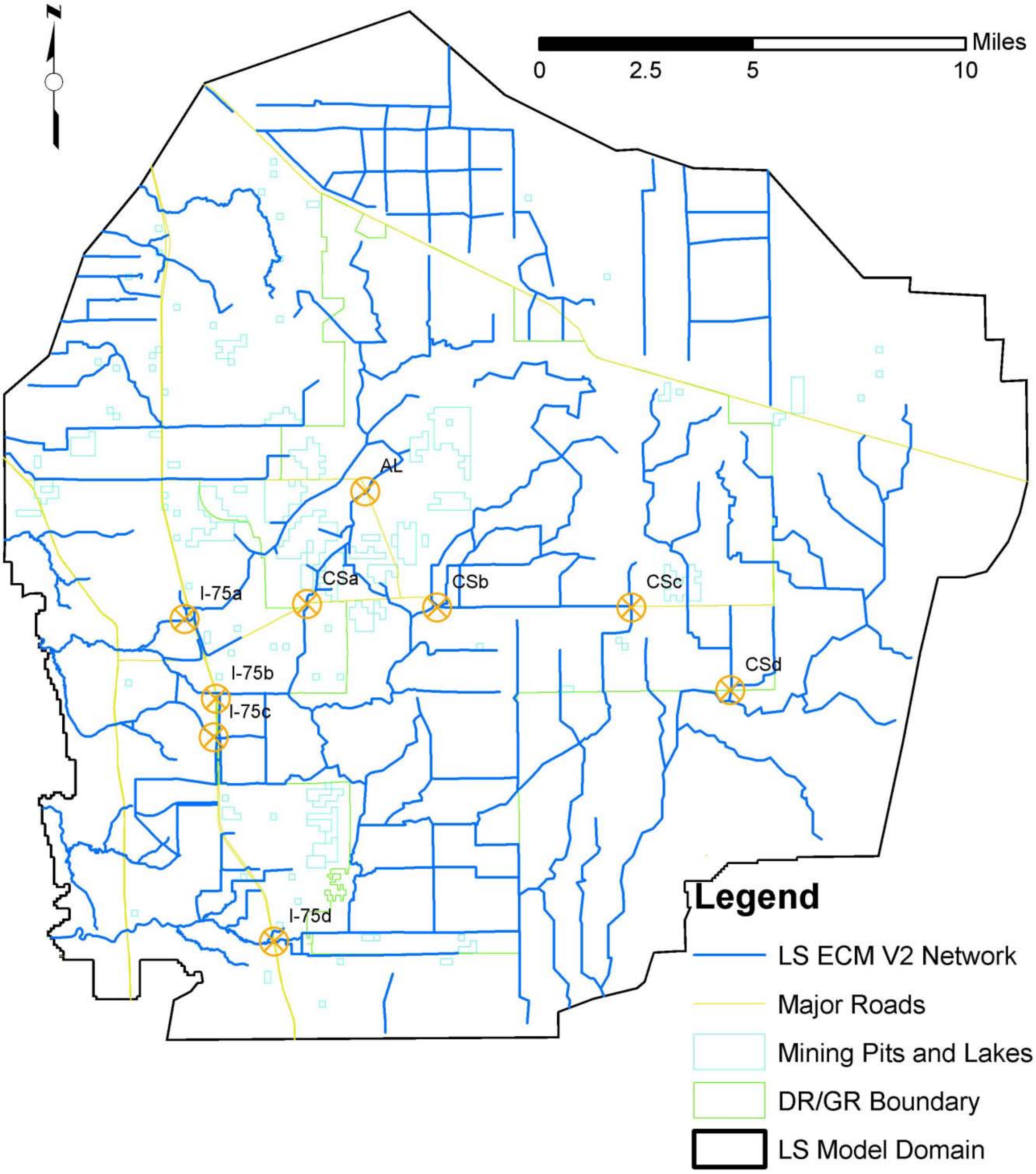

Figure 97. Selected flow comparison locations.

Conclusions

General Findings

The model results from the different land use scenarios indicate several concepts that may be useful during the planning process.

- Wetland areas converted from agricultural areas in the future condition alternatives help to increase the water table elevations during the dry season and to extend the period of time that those areas are wet (hydroperiod).

- The conversion of natural and agricultural areas to urban development slightly lowers the water table during the wet season due to the new urban drainage system. The water table in the new urban areas is usually higher at the end of the dry season compared to the existing conditions, which is likely related to a reduction in the ET losses.

- The water budget in all mines and lakes around the DR/GR Area suggests that the annual net rainfall (rainfall minus evaporation) is about zero on average. This is a consequence of the open water evaporation rate, which is commonly higher than the annual ET rate in pre-mined conditions. The model also predicts that the drainage system around some mines produces a positive net water outflow from the mines. As a result, the aquifers need to supply water to the mining pits (negative net groundwater recharge) in about the amount that is lost through the drainage system.

- This modeling has indicated, in general, that the annual averaged ET rates from the DR/GR Area would be higher with greater areal coverage of mining pits. The surface water outflow rate (runoff) from the DR/GR Area was lower in all the scenarios compared to the ECM, which is likely related to the greater mining pit coverage. These results are expected due to the higher ET losses and the lower runoff from mining pits and its effect on the surface water flow in neighboring areas.

- Mining pits cause a flattening in the water table that affects the pre-developed water table gradient. This often implies a decrease in the water table elevation on the up-gradient side of the pits and an increase on the down-gradient side. On the down gradient side, there may also be a decrease in some situations. The most pronounced flattening effect is seen towards the end of the dry season. This also has an effect on the hydroperiod by shortening the up-gradient hydroperiod and increasing (or sometimes also decreasing) the down-gradient hydroperiod. The flattening effect of mine development on the water table is larger in areas with steeper water table gradients, in larger mine pits, and in the case of a number of mining pits that are closer and therefore more hydrologically connected (i.e. via groundwater).

The expected qualitative effects of the different land use changes listed above are based on general model predictions generated by this study. In the future, uncertainty associated with these model results can be improved as more field data becomes available. In particular, as groundwater level data near the mining pits becomes available in the future, the model calibration will improve and the results around mining pits will be more representative of observed field data. Furthermore, the combined effect of the land use changes on water table elevation and hydroperiod may vary from one location to another and also from year to year. Thus, it is important to observe the results obtained from the different models at specific areas and times.

Recommendations for the Planning Process

The evaluation of the performance of the four future condition scenarios was based on several performance indicators extracted from the water table, hydroperiod and water budget sections. They are normalized in the interval (0, 1), where "0" represents the driest and "1" the wettest conditions from the four scenarios. The normalized indicators are shown in **Table 22**. The value of the indicator for the LS ECM was also estimated by using a mean difference of zero before normalizing. Water budget indicators for the LS ECM were not considered since they were far from the FCM range. In the case of the groundwater outflow from the ECM, it is not appropriate since it may be affected by the use of a different pumping rate in the FCMs with respect to the LS ECM. An average indicator (or score) for each scenario was computed by assuming a uniform weighting between them. Scenarios that are better for the water resources score higher average indicator values, and scenarios that are worse for the area water resources score lower average indicator values. From the average indicator, the FCM4 is the best scenario due to a variety of factors which includes a smaller number of mining pits compared to the acreage of restored land. These factors actually make FCM4 wetter on average than the LS ECM. Scenario FCM3 is the driest followed by FCM2.

Table 22. Normalized indicators to evaluate the scenario performance.

Section	Indicator (normalized)	ECM	FCM1	FCM2	FCM3	FCM4
Water Table Maps (Table 14)	Dry season water table level mean difference	-0.06	0.00	0.14	1.00	0.51
	Wet season water table level mean difference	0.82	0.26	0.37	0.00	1.00
Hydroperiod maps (Table 15)	Hydroperiod mean difference	0.91	0.54	0.35	0.00	1.00
	Water depth mean difference during hydroperiod	1.01	0.68	0.72	0.00	1.00
Water Budget (Table 17)	Annual averaged ET losses	---	0.80	0.32	0.00	1.00
	Annual averaged GW outflow	---	0.71	0.00	0.50	1.00
	Average indicator	0.67	0.50	0.32	0.25	0.92
Land use Changes	New mining pit area in DRGR (%)	0.00	4.90	7.42	9.35	6.35
	Restored area in DRGR (%)	0.00	3.11	5.14	6.28	7.81
	Restored minus new mining pit area in DRGR (%)	0.00	-1.79	-2.28	-3.07	1.46

The areal extent of the land use changes is also presented in Table 22 for the new mining pit and restored areas. In **Figure 98**, the average indicator is plotted as a function of the difference between newly restored minus new mining pit area. In this graph, the difference between the newly restored land and new mining pit areas comes from the new mining pit area and restored area rows in Table 22. As the percent of new mining pit area decreases, the resulting difference will be more and more positive. In the graph shown in Figure 98, this will correspond to the data point moving toward the right along the x-axis, which corresponds with an increasing average indicator value (or score) within the known data domain.

The almost perfect correlation in this graph may be helpful for the planning process. This correlation indicates that the restored (mitigated) area should be about equal to the new mining pit area in order to maintain, on average, the water table levels, hydroperiod and water budget in the entire DR/GR area. If the restored areal extent is greater than the new mining pit areal extent (which is the case in FCM4), this relationship suggests that scenario should be wetter than the ECM. The smaller the areal extent of the restored areas with respect to the areal extent of the new mining pit areas, the drier this relationship predicts the scenario to be.

The correlation shown in Figure 98 also enables the estimation of the performance of new scenarios based on one of the four FCMs. The impact of adding new restoration areas or mining pit areas can be quickly estimated from this graph, without a need to develop a new MIKE SHE model. However, these correlations are only valid within the range of values that have been simulated to date. Also, these are only valid for restoration areas or mining pit areas in the vicinity of those modeled to date. Therefore, the new mining pit areas and restored areas should be limited to the locations simulated in the four FCMs, and also in the range of areal extents considered.

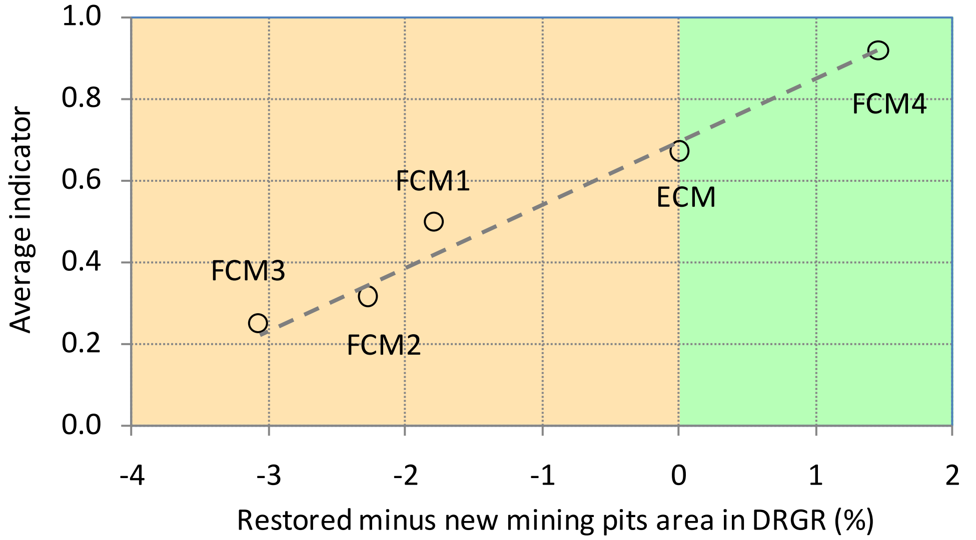

Figure 98. Correlation between the average indicator (score) of each scenario and the land use changes for the DR/GR Area.

Another recommendation for the planning process arising from this work is related to where to locate the new mining pits. In order to avoid mining impacts to water table levels and hydroperiods with respect to the current conditions, the flattening effect mentioned above should be minimized. There are two requirements to this, as demonstrated in the modeling results. One is to locate the mining pits in areas with flat topography (and flat water table, assumed to mimic the land surface). The second is to separate the mining pits by some critical distance in order to minimize their hydrologic connectivity. It is acknowledged that both of these requirements may not be achievable due to prior approvals granted for mine pits that are on sloping topography and/or are not adequately separated to minimize hydrologic connectivity. This study did not explore the critical gradient slope or critical spacing between mining pits, though.

Model Limitations and Recommended Future Work

The MIKE SHE model was developed based on the best available data at the time with a state of the art, fully integrated modeling package. However, as with any other model, there may be some opportunities for improvement.

1. **Revision of pumping data.** Pumping data is a source of uncertainty in all hydrologic models. The pumping rates and the pumping depths are not well known, in general. However, production rates can have a tremendous influence on groundwater heads. In this work, the time to collect that information was limited and its review is recommended in any future work.
2. **Revision of the hydro-geologic data.** The vertical extent of the geologic layers and lenses in the model were extracted from the SWFFS model, as indicated in the project

scope. The hydraulic conductivity, specific yield, and storage coefficient were also taken originally from the same model, and modified during the calibration process. All hydrogeologic parameters could be reviewed from the information available in DBHYDRO.

3. **Inclusion of the Hawthorn Aquifer in the model.** Because of the intensive pumping from the Hawthorn Aquifer and the poor prediction of the heads in the Sandstone Aquifer, the evaluation of the introduction of deeper layers in the model is recommended.
4. **Revision of the drainage system around mining pits.** The drainage system around some mining pits was introduced in the model based on available LIDAR data. However, the incoming and outgoing flows predicted by the model at mining pits could not be verified with observation data. Since those flows are important for the water budget and the surface flow reliability of the model, the review of the drainage system around mining pits is recommended as data become available.

Note that even with the proposed improvements listed above, the model has limitations related to the grid cell size (750 ft). For local studies that require a higher resolution, the construction of a new model with a smaller model domain area and grid cell size is recommended.

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