Comparison of Average Annual Precipitation Distributed by Different GIS Models for the Bitterroot Watershed, Montana [1]

by Robert G. Hammer, Phillip E. Farnes, and Robert A. McLeod [2]

Introduction

In 1995, the Bitterroot National Forest initiated a watershed analysis of the Bitterroot Mountains called, Stevensville West Central. The GIS precipitation layer was a 4 km grid PRISM model. The 4 km PRISM model showed an obvious inaccuracy in the amount of precipitation in the Big Creek drainage, and this 2.5 km wide mountain canyon had a precipitation maximum shown about 2 km downwind of the Bitterroot Divide. This prompted an investigation into other available methods that would more accurately represent annual precipitation. The 4 km scale of PRISM modeling is inadequate to accurately determine precipitation on smaller drainages in mountainous terrain and is not used in comparisons.

The Bitterroot River in southwestern Montana is fed by water from the steep glaciated Bitterroot Mountains along the Montana-Idaho border on the west side of the drainage and the Sapphire Mountains on the east side. Average annual precipitation ranges from 300 mm in the lower valley to over 2500 mm in the Bitterroot Mountains. Precipitation in the Bitterroot Mountains is twice that in the Sapphire Mountains at comparable elevations. Elevations range from 850 m in the valley to 3000 m in the mountains. This varied landscape is a good area to compare GIS mapping models that spatially distribute precipitation.

Analysis

The 1961-90, 30 year average annual precipitation data was used for the digitized hand drawn precipitation map and to generate GIS developed precipitation maps using the PRISM, MTCLIM, and ANUSPLINE models. These are shown in figures 1 - 5. Areal percentages of precipitation by 250 mm increments are compared between models. Precipitation for the entire Bitterroot River and for localized tributary watersheds is compared for the various models.

The steep Bitterroot Mountains on the west side of the Bitterroot River were selected to illustrate GIS precipitation mapping comparisons in four watersheds. The four west side watersheds are Big Creek, Lost Horse Creek, Rock Creek, and West Fork Bitterroot River. On the more gentle Sapphire Mountains east of the Bitterroot River, only one watershed, Skalkaho Creek, was selected. Watershed areas for the Bitterroot River, Big Creek, Lost Horse

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Creek, Rock Creek, West Fork Bitterroot River, and Skalkaho Creek are 6380, 90, 1170, 140, 1460, and 310 square kilometers, respectively. Areal distribution by elevation class is shown in Figure 6.

Some precipitation data points adjacent to the the Bitterroot River drainage were used in the GIS modeling. Table 1 shows the area weighted average annual precipitation by watershed and GIS model. Figures 7 to 12 show percentage of the area in each precipitation class for each GIS model for the six watersheds.

Conclusions

Average annual precipitation values for large watersheds such as the Bitterroot River and for smaller watersheds are similar for all GIS models except for PRISM 2 km scale. It appears that PRISM on 1 km or less scale is needed to represent mountain precipitation.

Since elevation is used to drive most GIS models, it is imperative that the scale be adequate to approximate the terrain. If the scale is so gross that it doesn't represent the terrain, then resulting precipitation maps can't be expected to truly represent the precipitation. Likewise, measuring station locations should be identified to the nearest second rather than to the nearest minute of latitude/longitude as shown in most databases.

Even though watershed average precipitation is similar, only Farnes and MTCLIM methods share isohyetal lines that correspond to measured precipitation values. PRISM and ANUSPLINE develop algorithms for larger areas, and isohyetal lines may not agree with precipitation measured at a specific data site.

The distribution of precipitation across watersheds shows considerable variation between methods. Where there are no data stations in the highest elevations such as the west side of the Bitterroot, ANUSPLINE fails to account for higher precipitation values in highest elevations.

Both ANUSPLINE and PRISM use clusters of many stations to develop elevation versus precipitation algorithms whereas the hand drawn method and MTCLIM use a more localized profile of stations within a smaller area. This permits these methods to represent localized rain shadow or precipitation enhanced areas. ANUSPLINE and PRISM are less sensitive to these microclimates. In this area, a good example is the data site at Lolo Pass on the northwest corner of the drainage. Here, the narrowing of the upwind drainages creates more precipitation at the pass than occurs at other areas in the Bitterroot at comparable elevation. This area of enhanced precipitation covers a relatively small area. However, PRISM and ANUSPLINE assume this precipitation pattern exists over a much greater area. Also, depending on th number of available data stations, both methods will incorporate data sites from both the east and west side of the drainage, hence, showing more than the actual precipitation in the Sapphire Range (east side) and less than the actual precipitation in the Bitterroot Range (west side).

Users of GIS generated precipitation maps need to be aware of how each method analyzes the measured data and the extent of area or number of data sites incorporated in elevation versus precipitation algorithms so they can determine which method might best fill their needs.

References for GIS Precipitation Mapping Methods

Phil Farnes produced the first average annual precipitation maps for Montana that incorporated high elevation snow survey data. Current Bitterroot maps were developed using data from National Weather Service climatological stations, SNOTEL sites, storage gages, and snow courses. Refer to "Mountain Precipitation and Hydrology From Snow Surveys," 1971, in the Proceedings of the 39th Western Snow Conference, and "Estimating Monthly Distribution of Average Annual Precipitation in Mountainous Areas of Montana," 1995, in the Proceedings of the 63rd Western Snow Conference. Terrain mapping precipitation elevation relationships are localized for regional areas of similar precipitation patterns.

Oregon State University, through the Oregon Climate Service, creates PRISM modeled average annual, seasonal, and monthly precipitation maps for the Natural Resources Conservation Service. Refer to the "PRISM Briefing Book and Questionnaire, a Description of the PRISM Model for Spatially Distributing Observed Precipitation," by the above mentioned agencies, 1995. Digital elevation model terrain and data points are related by topographic faces.

The University of Montana developed the MTCLIM model to extrapolate daily oservations of meteorological data to remote sites in complex terrain. Refer to Peter Thornton, Steve Running, and Michael White, "Generating Surfaces of Daily Meteorological Variables Over Large Regions of Complex Terrain," 1996, Journal of Hydrology, BAHC Symposium "Tucson Aggregation Workshop." Peter Thornton graciously provided the Bitterroot mapping with MTCLIM.

Montana State University provided the ANUSPLINE mapping for the Bitterroot through the help of Sara Stillman. Refer to "A Comparison of Three Automated Precipitation Simulation Models: ANUSPLINE, MTCLIM-3D and PRISM," 1996, Sara's Master of Science thesis. ANUSPLINE was developed at Australian National University.

Table 1. Average Annual Precipitation for 1961-90 Period for Selected Watersheds In Bitterroot River by Different GIS Methods

Average Annual Precipitation (mm)

	Rock Cr	Lost Horse	West Fork	Skalkaho Cr	Big Cr	Bitterroot R
Farnes	1648	1524	1024	770	1240	876
MTCLIM	1768	1453	980	749	1143	833
ANUSPLINE	1300	1260	1006	780	1158	866
PRISM 1km	1356	1400	950	732	1494	856
PRISM 2km	899	914	841	648	907	792

	Farnes	MTCLIM	ANUSPLINE	PRISM 1km	PRISM 2km
Rock Cr	1648	1768	1300	1356	899
Lost Horse	1524	1453	1260	1400	914
West Fork	1024	980	1006	950	841
Skalkaho Cr	770	749	780	732	648
Big Cr	1240	1143	1158	1494	907
Bitterroot R	876	833	866	856	792

Figure 6. Percentage of Area by Elevation Class for Selected Watersheds, Bitterroot River, Montana

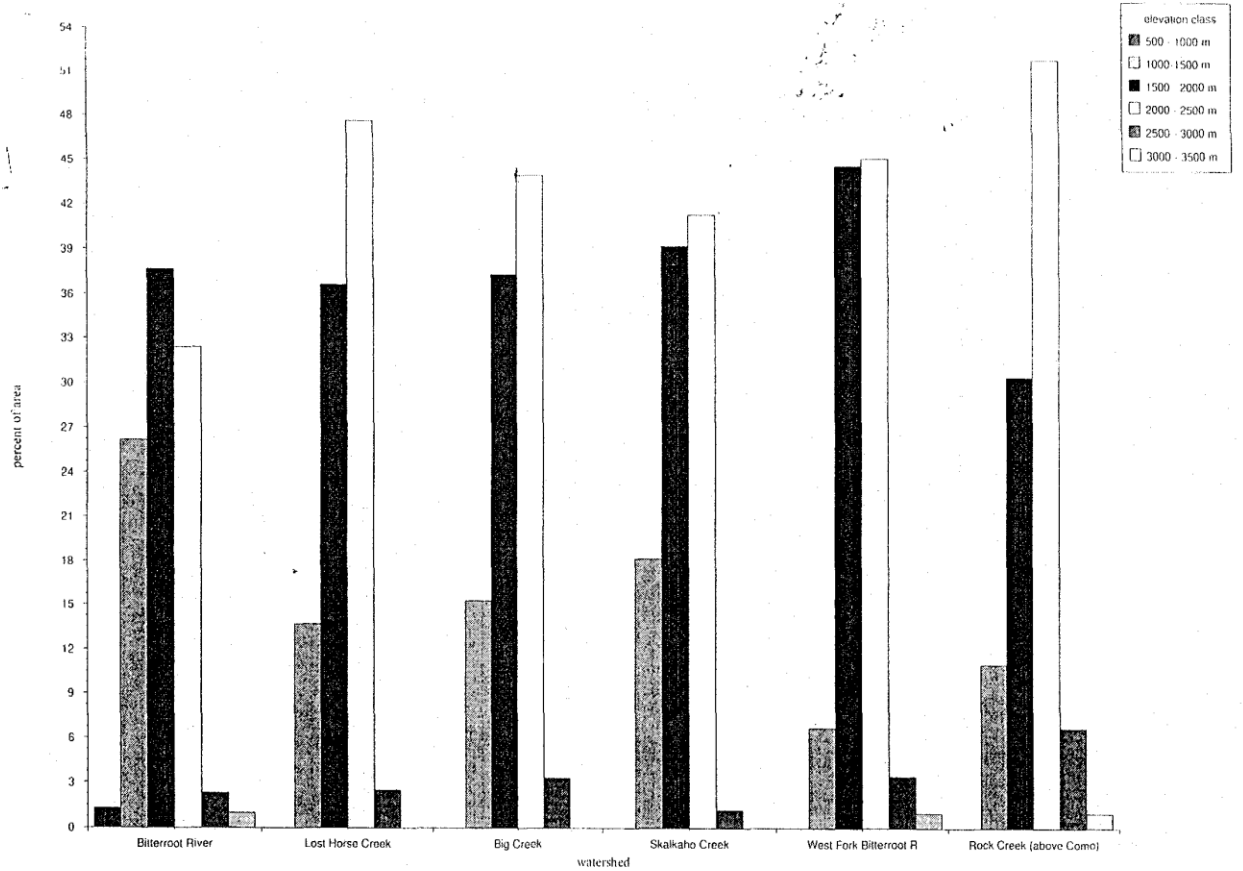
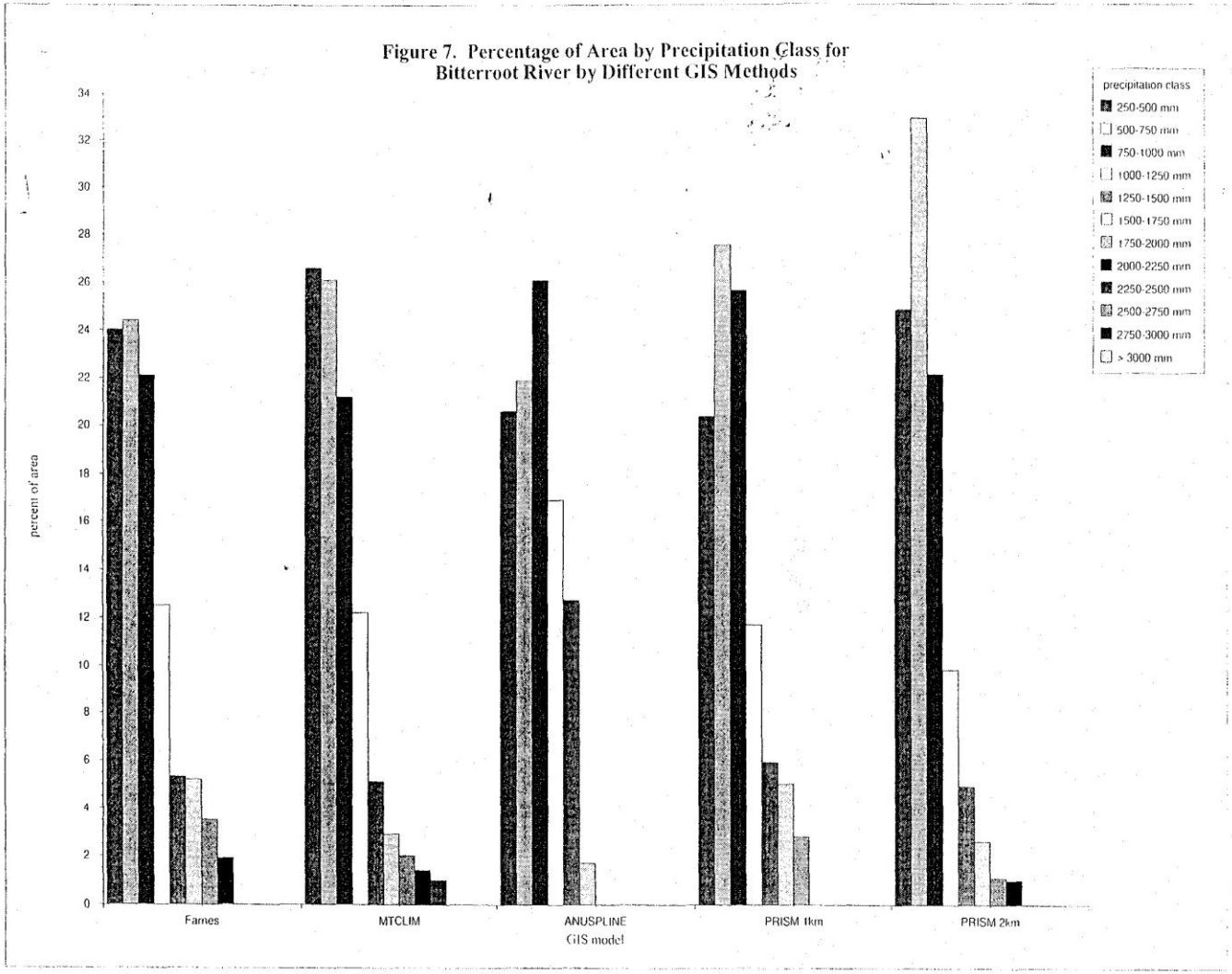


Figure 7. Percentage of Area by Precipitation Class for Bitterroot River by Different GIS Methods



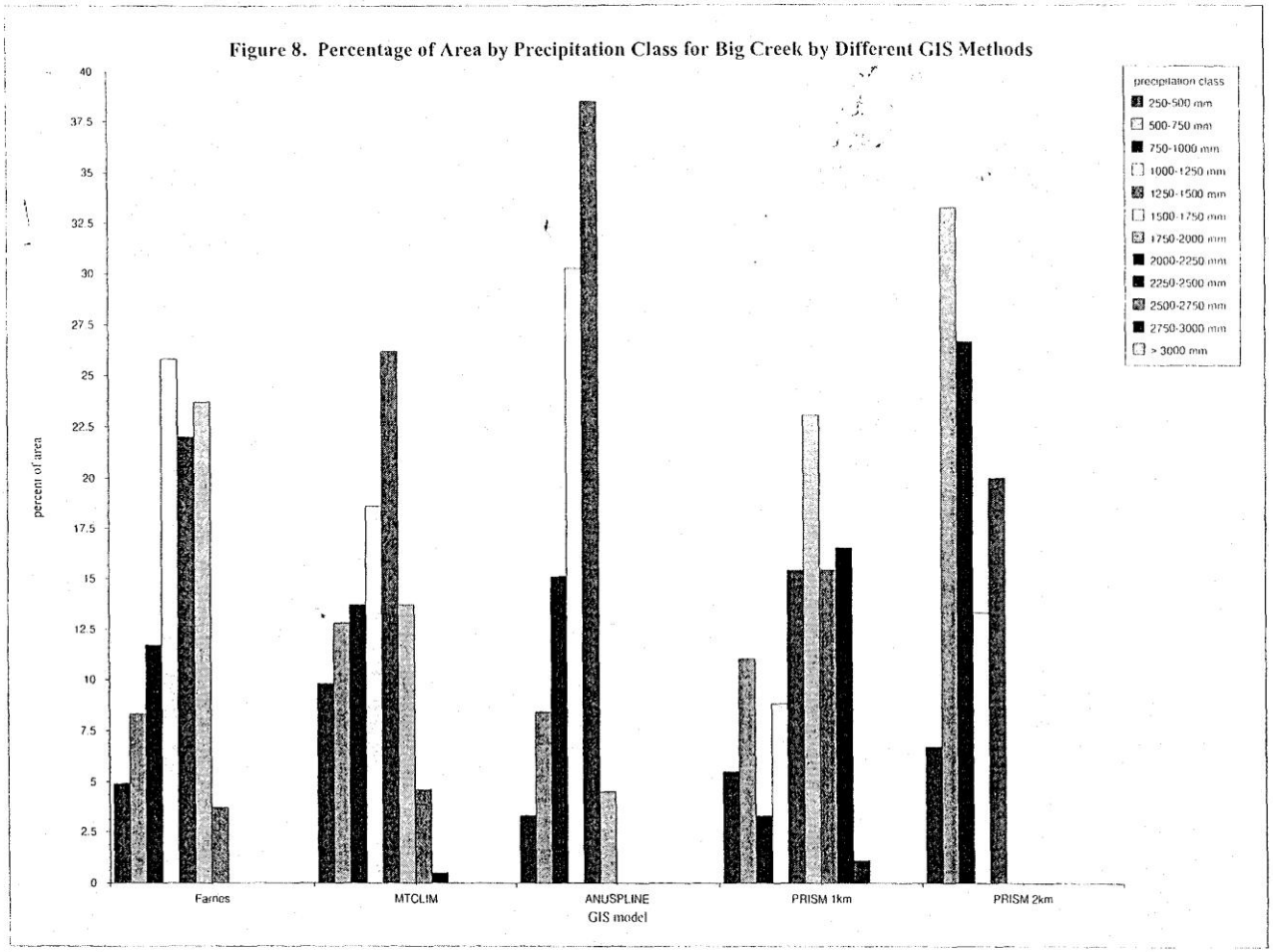


Figure 8. Percentage of Area by Precipitation Class for Big Creek by Different GIS Methods
precipitation class
250-500 mm
500-750 mm
750-1000 mm
1000-1250 mm
1250-1500 mm
1500-1750 mm
1750-2000 mm
2000-2250 mm
2250-2500 mm
2500-2750 mm
2750-3000 mm
> 3000 mm
percent of area
40
37.5
35
32.5
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
Farnes
MTCLIM
ANUSPLINE
PRISM 1km
PRISM 2km
GIS model

Figure 9. Percentage of Area by Precipitation Class for Lost Horse Creek by Different GIS Methods

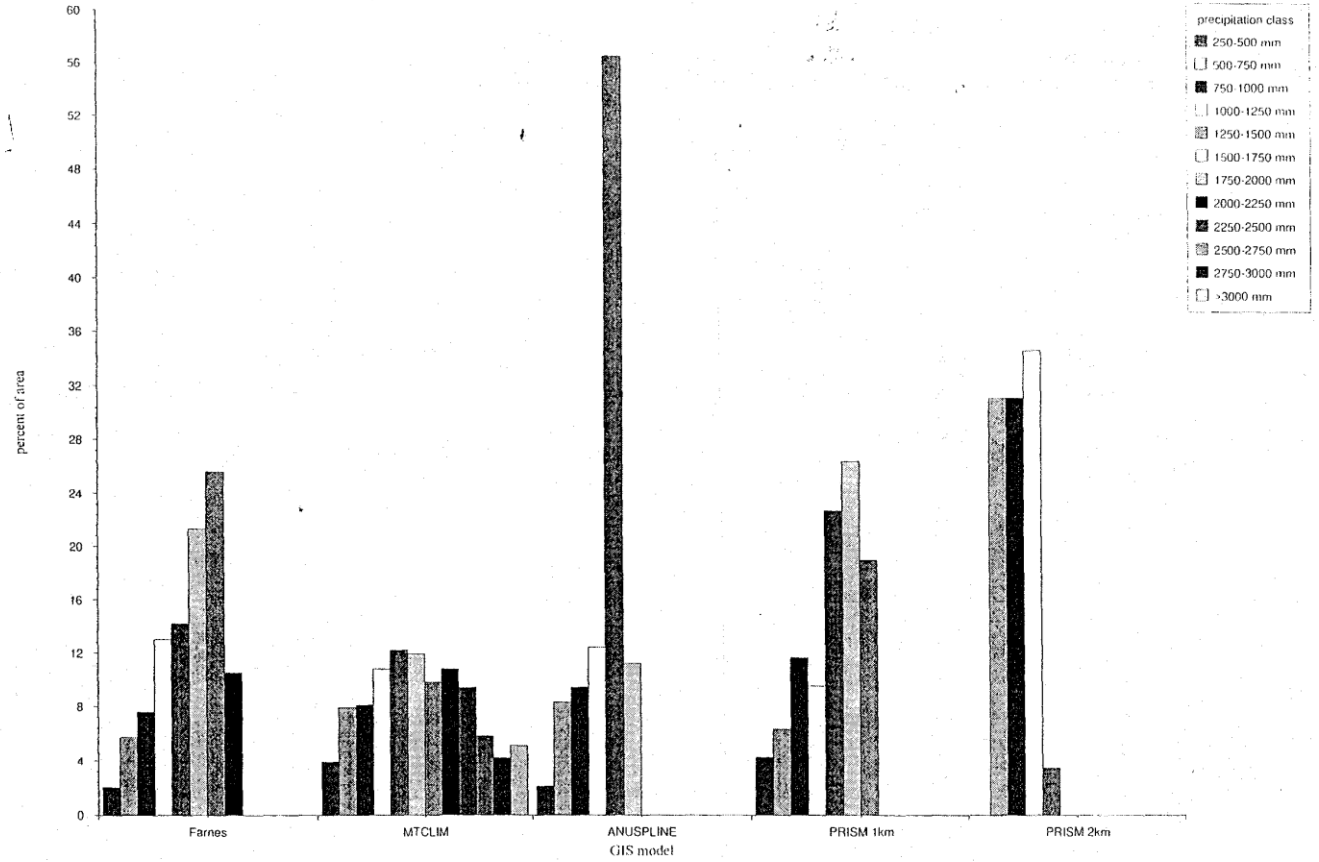


Figure 10. Percentage of Area by Precipitation Class for Rock Creek by Different GIS Methods

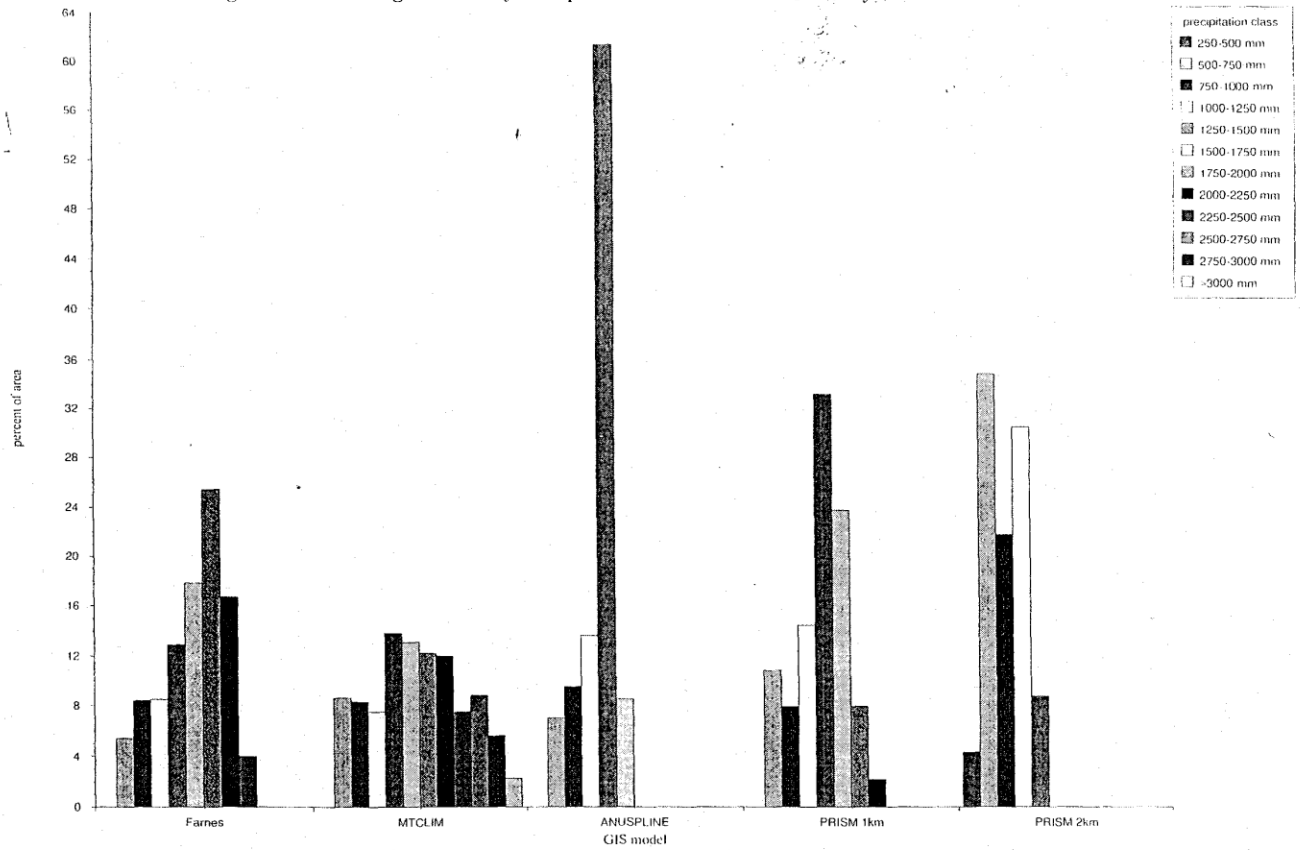


Figure 11. Percentage of Area by Precipitation Class for West Fork Bitterroot River by Different GIS Methods

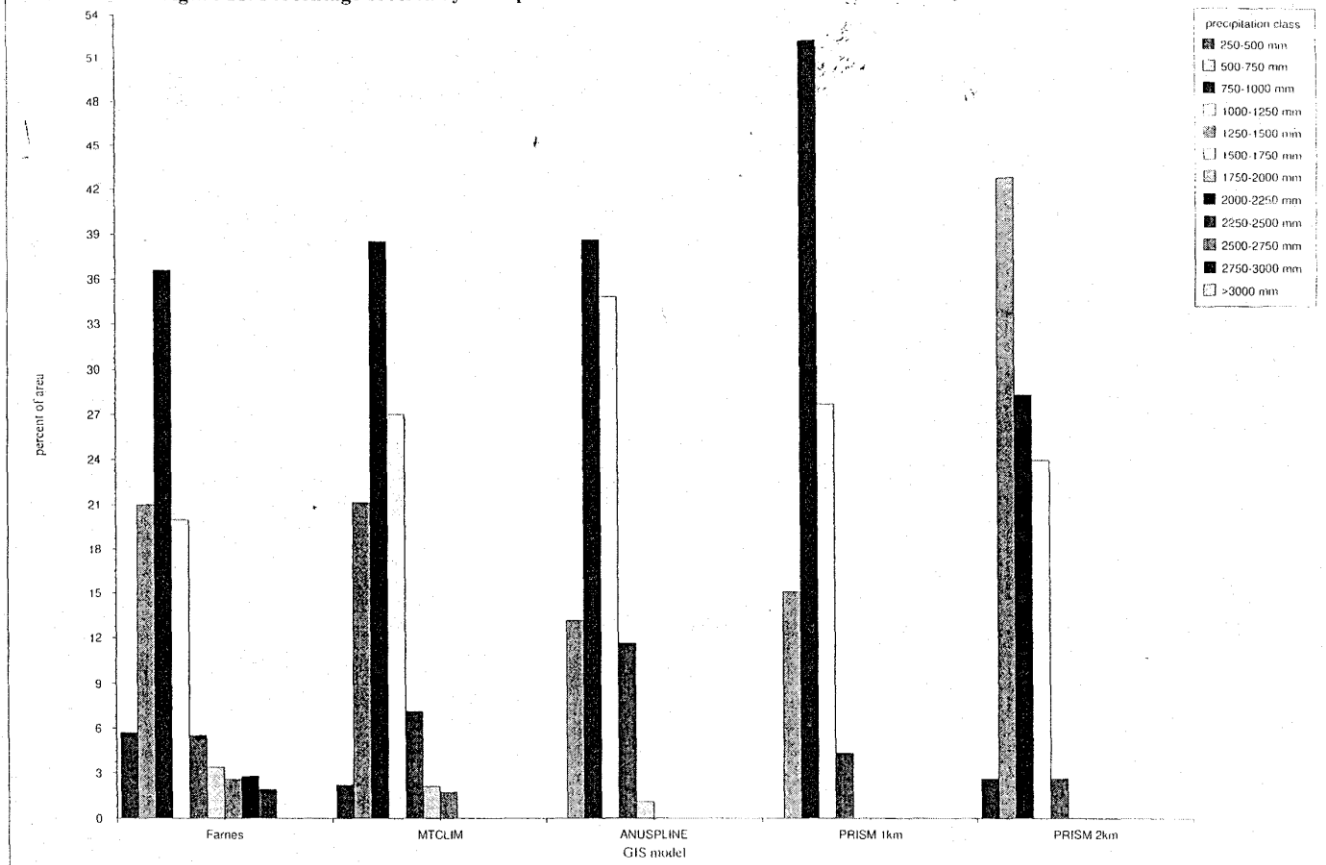
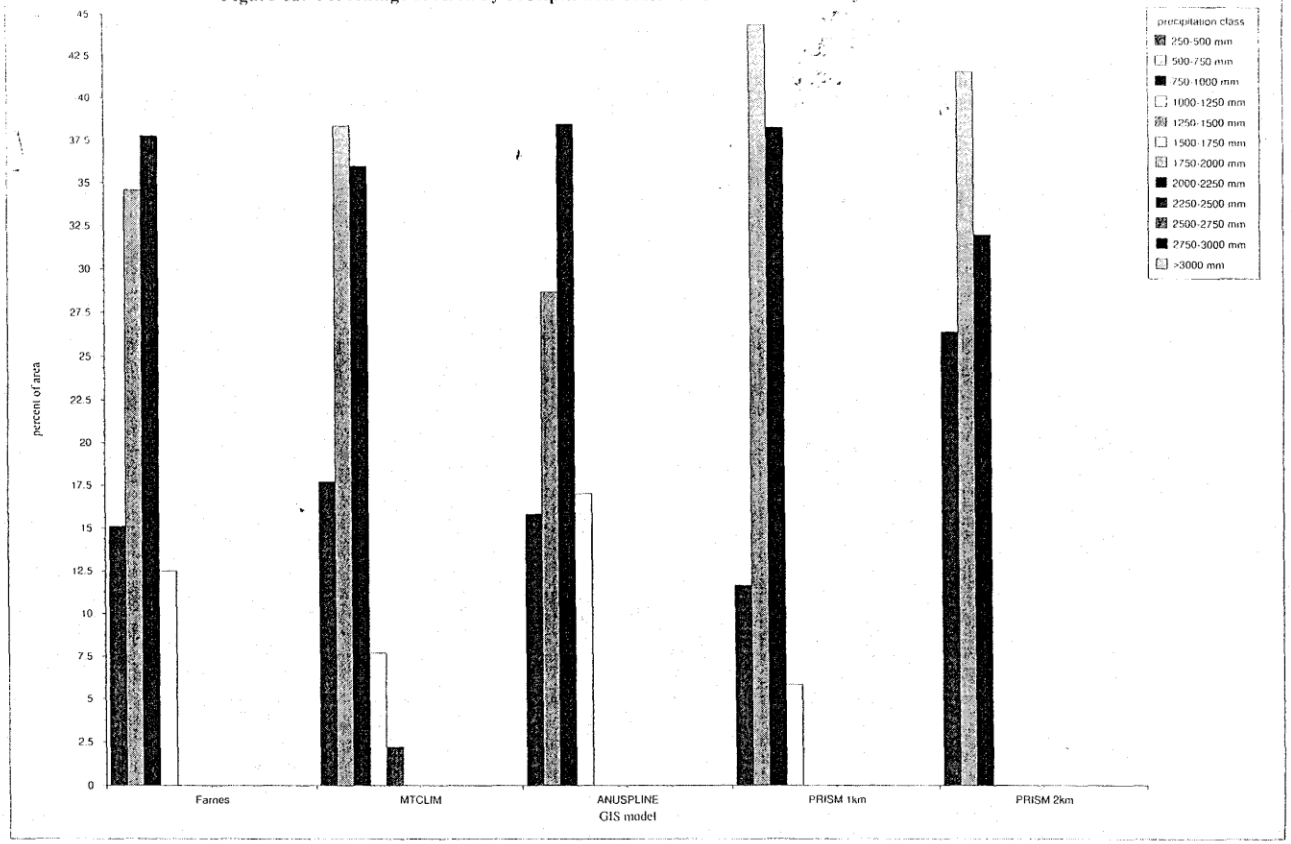


Figure 12. Percentage of Area by Precipitation Class for Skalkaho Creek by Different GIS Methods



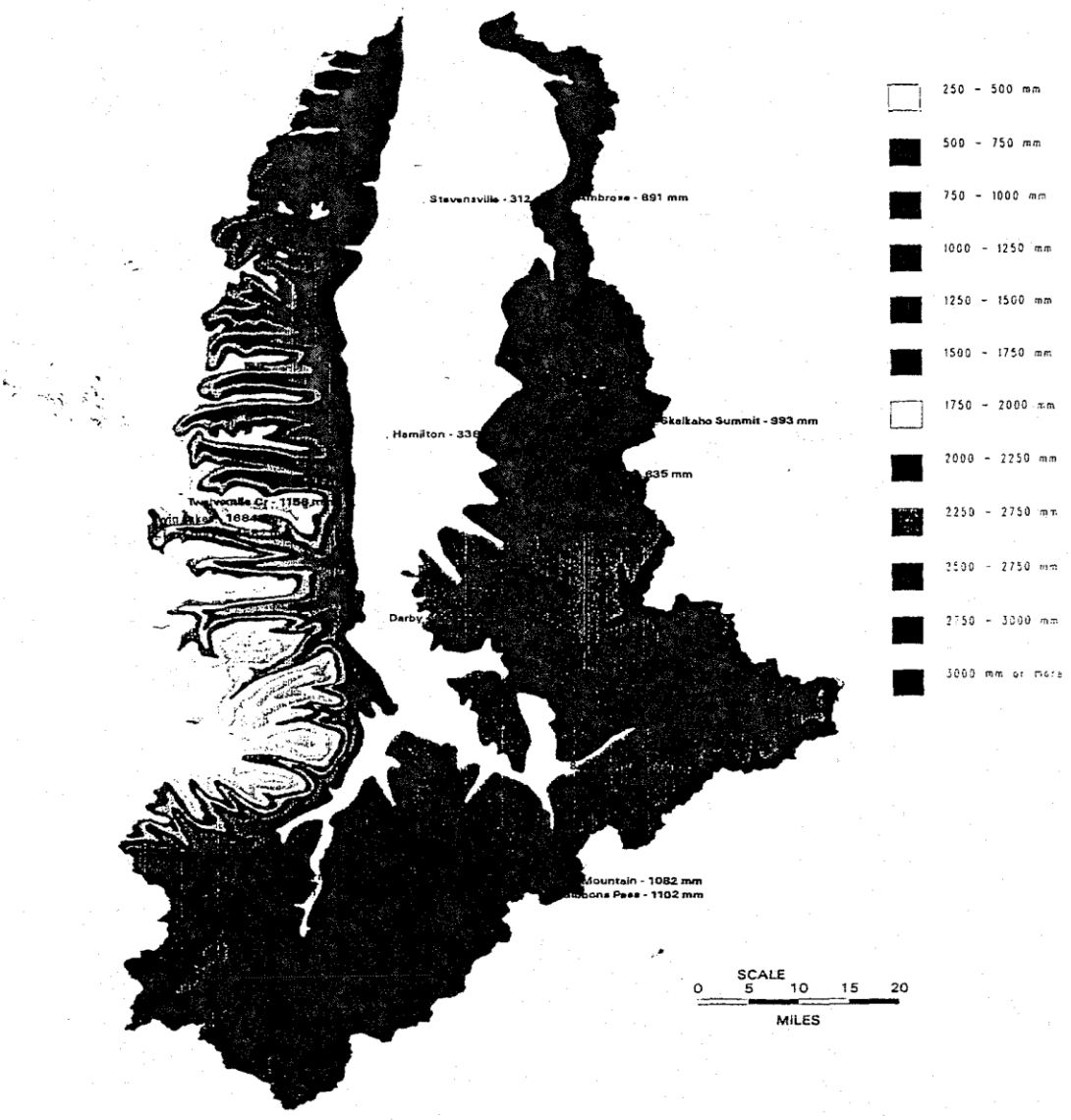


Figure 1. Average Annual Precipitation, 1961-1990, for Bitterroot River Drainage by Farnes.

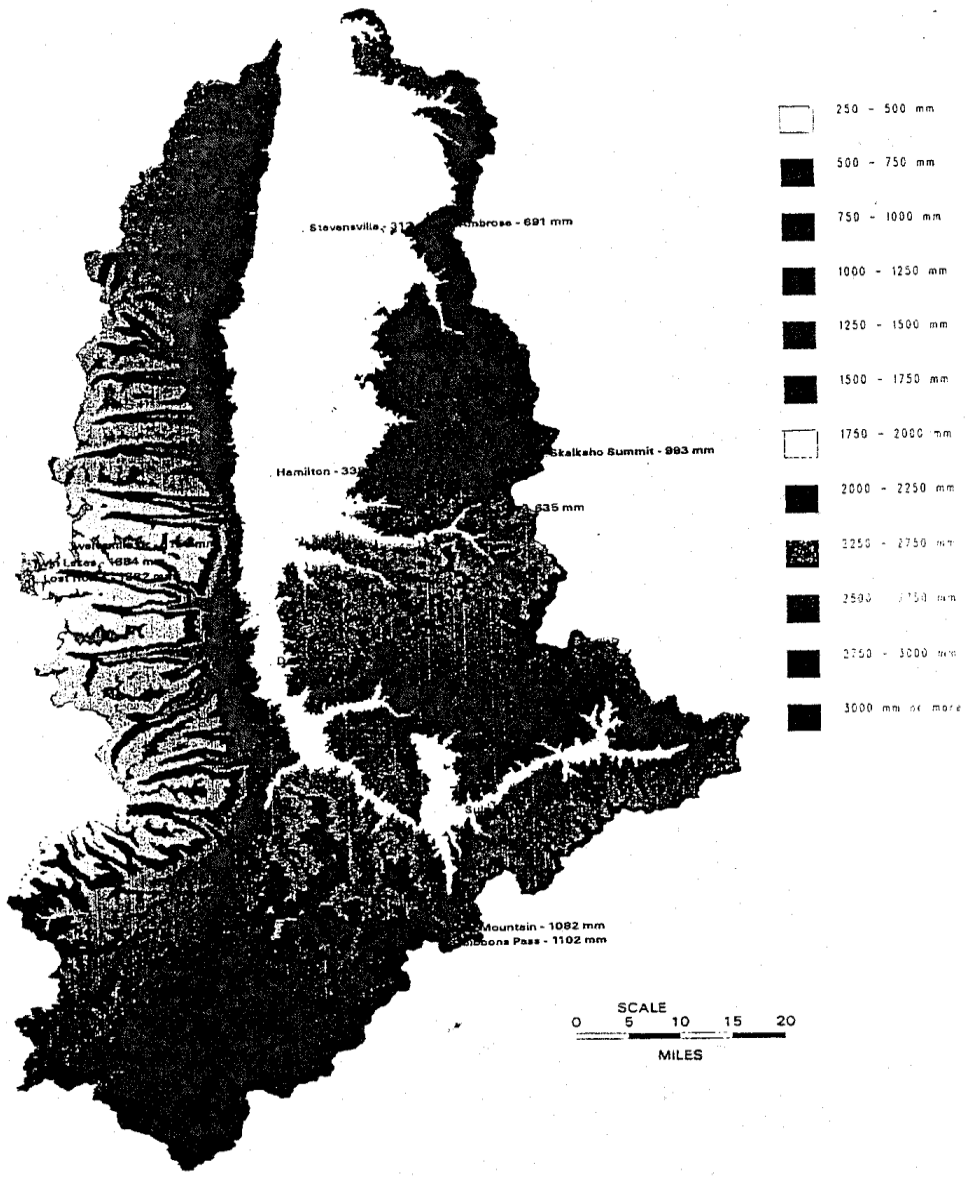


Figure 2. Average Annual Precipitation, 1961-1990, for Bitterroot River Drainage by ANUSPLINE with 90 m cells.

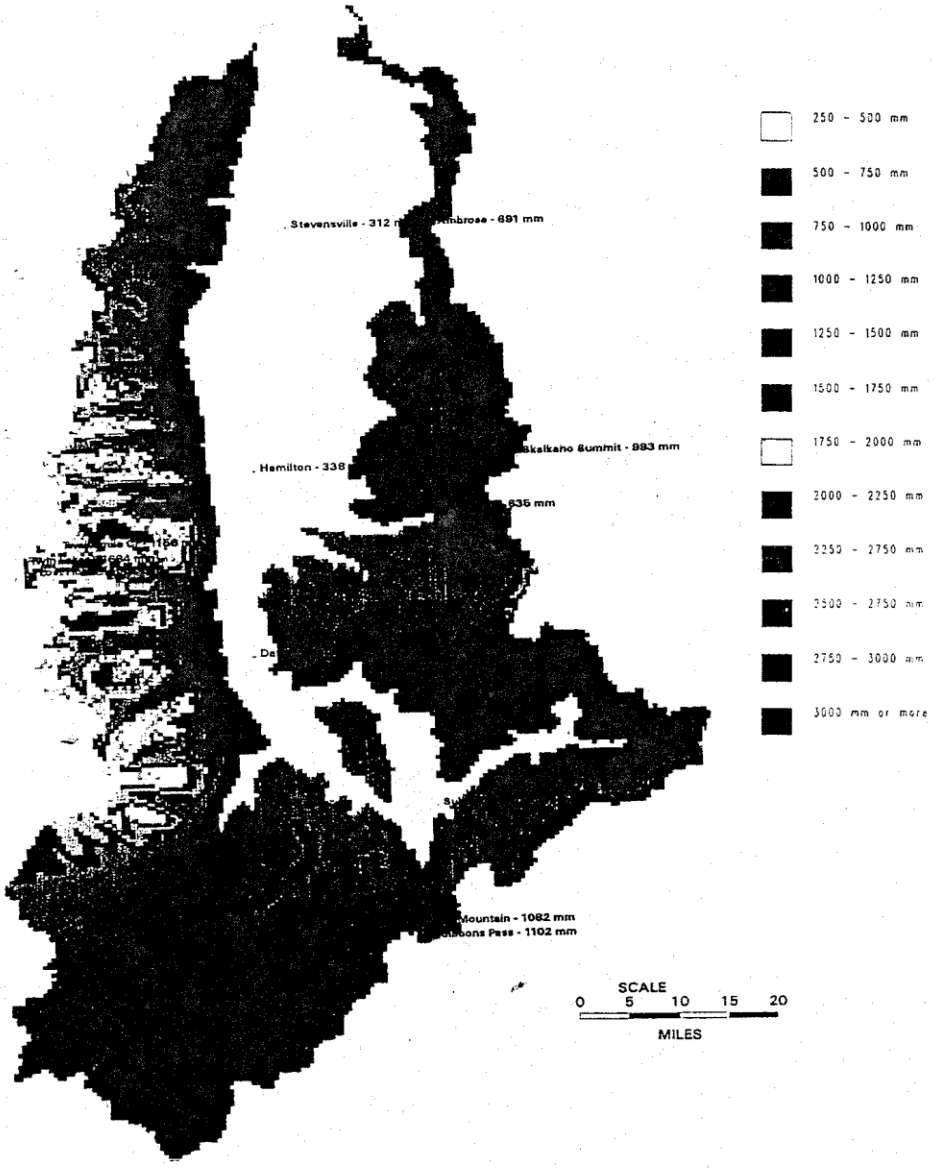


Figure 3. Average Annual Precipitation, 1961-1990, for Bitterroot River Drainage by MTCLIM with 500 m cells.

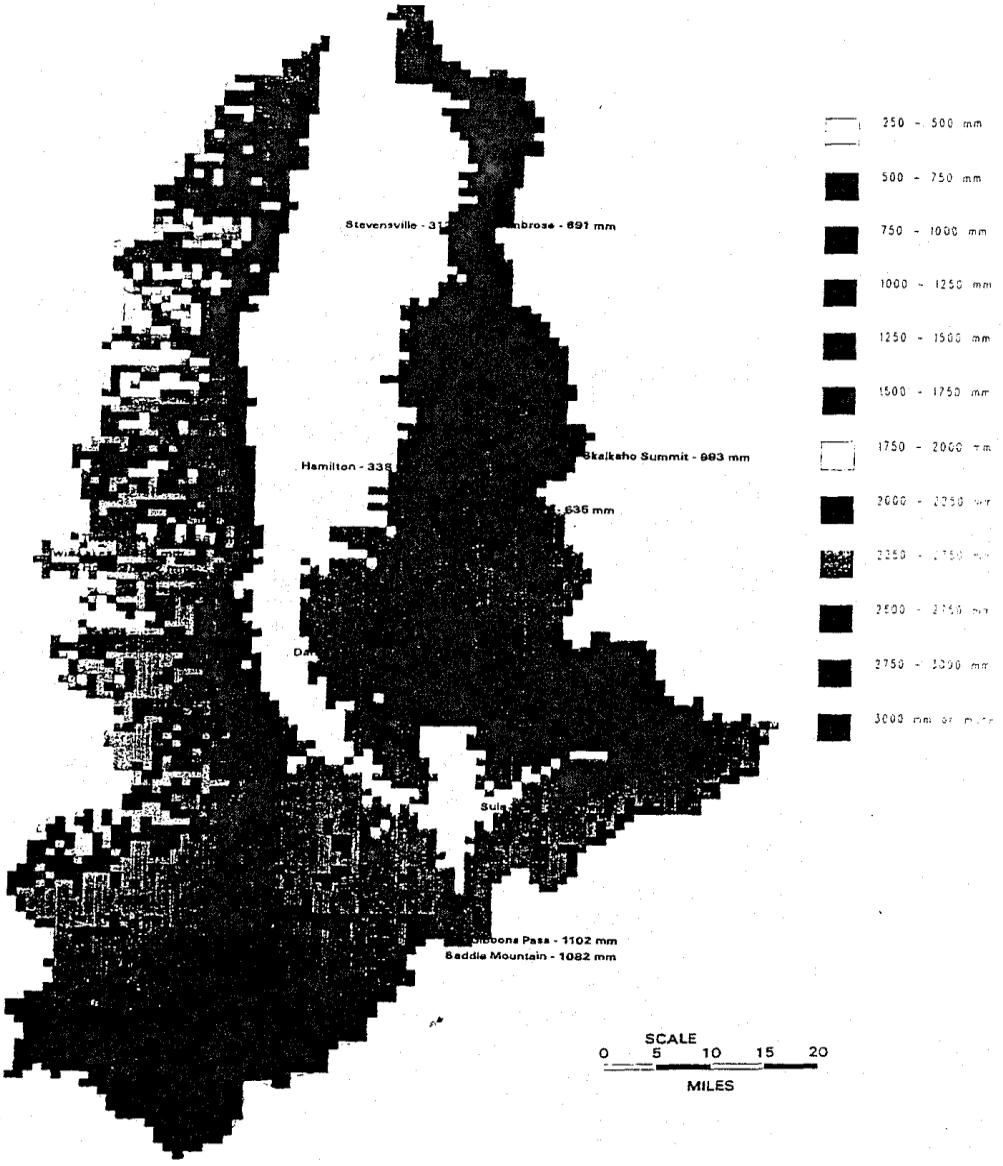


Figure 4. Average Annual Precipitation, 1961-1990, for Bitterroot River Drainage by PRISM with 1000 m cells (1 km).

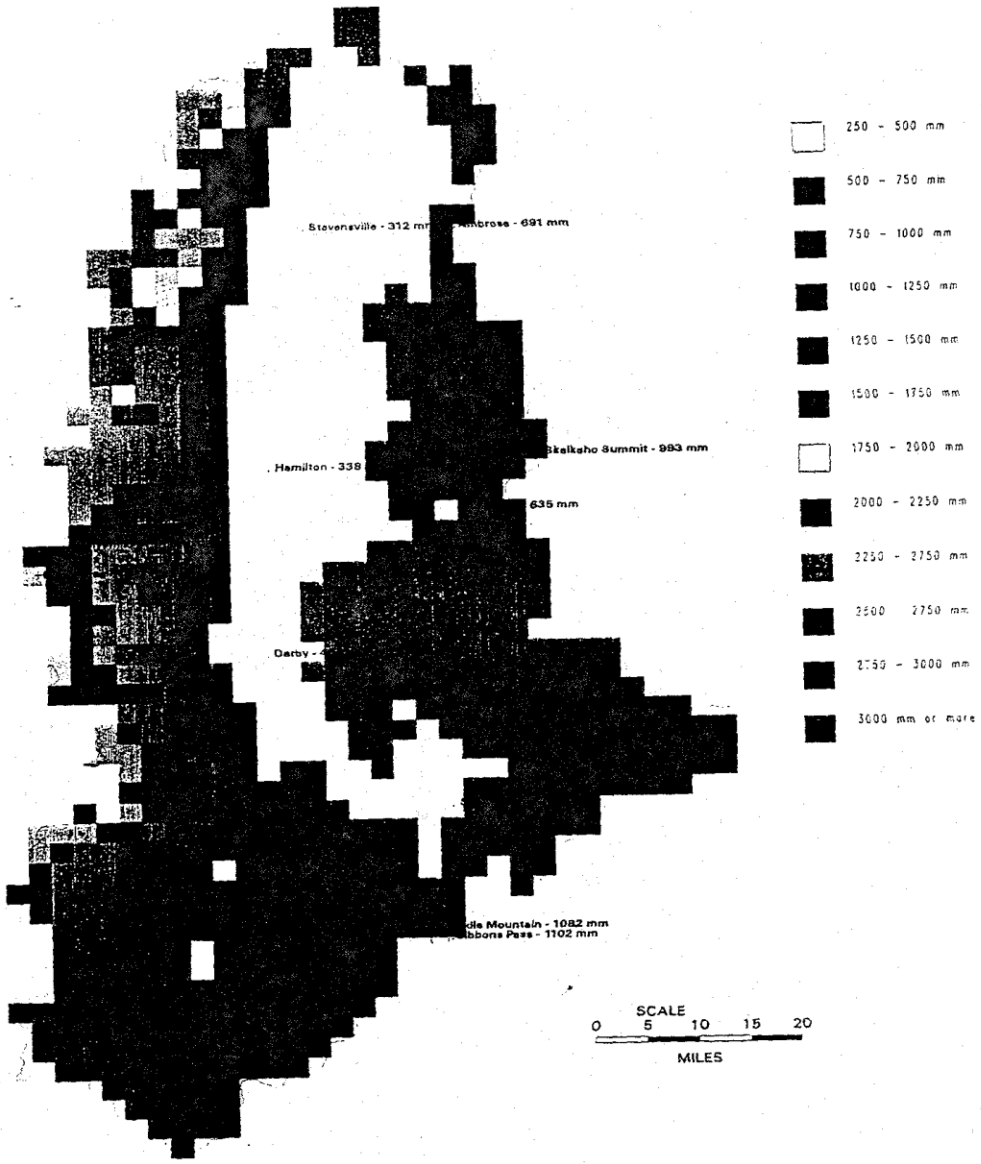


Figure 5. Average Annual Precipitation, 1961-1990, for Bitterroot River Drainage by PRISM with 2300 m cells (2 km).