Name: ______________________________ Date:____________________

SimWater: Simulating Water Supply, Demand, and Management

Mountains to Valley: Balancing forests, rivers, and downstream water users

Water managers are entrusted to best allocate water based upon the water available to them. They accomplish this by having a strong understanding of the water cycle, enabling them to develop a water budget that balances both societal and environmental water needs. The following activity will demonstrate some of the issues that water management agencies attempt to resolve, and provide a basic understanding for how they regulate complex systems of water storage, delivery, and consumption.

Use the SimWater: Mountains to Valley map for this activity. The map is a satellite image comprising the Kings River watershed and downstream regions in California. Valley and Mountains zones are designated on the map with orange and green tints, respectively. Meteorological stations are marked with yellow numbered circles. Rivers, streams, and lakes are shown in blue. Overlain on the map is a grid of 5 km by 5 km squares.

This activity requires several unit conversions. A few helpful conversions are provided below.

1 m = 1,000 mm　　　1 km = 1,000 m = 1,000,000 mm

1 m^2 = 1,000 mm x 1,000 mm = 1,000,000 mm^2　　　1 km^2 = 1,000 m x 1,000 m = 1,000,000 m^2

Section 1: Extrapolating Annual Precipitation and Water Balance Input

Eight meteorological stations measure precipitation for the region. Divide the map into eight equal *pixels* and draw a *centroid* (center point) for each pixel. Label each pixel on Map 1 with a number or other labeling code. Use Table 1b (next page) and inverse-distance weighting with the three nearest neighbors to extrapolate each pixel centroid to extrapolate precipitation (Equation 1).

Table 1a. Annual Precipitation

Met Station	Annual Cumulative Precip (mm)
1	1021
2	975
3	842
4	508
5	306
6	338
7	213
8	263

Equation 1. Inverse Distance Weighting With Three Nearest Neighbors

$$Precip_{pixel} = \frac{\sum(w_i * Precip_{annual_i})}{\sum w_i} \quad \text{where } w_i = \frac{1}{distance_i}$$

Example for an upper left corner pixel using neighbors 8, 6, and 7:

$$\frac{(\frac{1}{2.0} * 263) + (\frac{1}{5.5} * 338) + (\frac{1}{8.5} * 213)}{\frac{1}{2.0} + \frac{1}{5.5} + \frac{1}{8.5}} = 272.7 \text{ mm}$$

Activity by Michelle Gilmore & Joseph Rungee: University of California, Merced & Southern Sierra Critical Zone Observatory
Adapted from original SimWater activity by Ryan Lucas

Table 1b. Precipitation Extrapolation

Pixel Number	Nearest Met Stations	Distance From Centroid (cm)	Stations' Annual Cumulative Precips (mm)	Centroid Weighted Annual Precip (mm)

1) *What are the average weighted annual precipitations (mm) for the Valley and Mountains zones, separately? To obtain this value, use your completed Table 1b and average the precipitation values extrapolated for each centroid in the zone of interest.*

2) *Calculate water balance input of precipitation (m^3). To obtain this volume, multiply each centroid's precipitation by the area of each pixel; then sum each pixel's volume in the extent of interest. Hint: Each grid square is 25 km^2.*

   a. *What are the annual precipitation inputs (m^3) for the Valley and Mountain zones, separately?*

   b. *What is the summed annual precipitation input (m^3) for the entire map extent?*

Section 2: Balancing Forest and River Water Use

Large forests are found above a certain elevation in this region, seen in dark green on the right side of the map. Some precipitation input is removed from the surface water budget via evaporation and plant transpiration, known as evapotranspiration (ET). To monitor forest ET, four eddy-covariance flux towers are installed in the Mountains zone, co-located with meteorological stations 1-4 on the map. Instruments on the towers measure water vapor content in the atmosphere just above the tree canopy. These towers are placed at different elevations, which have differing vegetation diversity and abundance at each elevation.

Assume that ET measurements at each tower are representative for 1/4 of the area of the Mountains zone.

Table 2. 2020 Evapotranspiration

Flux Tower	Annual Cumulative ET (mm)
1	479
2	741
3	698
4	459

3) *Calculate forest water use.*

   a. *What is the annual volume of forest water use (m^3) for each flux tower's elevation band? To calculate this volume, multiply ET by the area of extent for each tower's measurements.*

   b. *What is the summed volume of annual forest water use (m^3) for the entire Mountains zone?*

4) *Calculate water runoff. The difference between precipitation input volume and forest water use provides an estimate of water runoff (P – ET = R).*

   a. *What is the annual water runoff (m^3) from the Mountains zone?*

   b. *What is the total annual runoff (m^3) for the entire map extent? Hint: ET and groundwater infiltration in the Valley zone is not factored into this region's annual water budget, so all Valley precipitation is assumed as runoff.*

5) *Runoff becomes water flowing in streams and rivers. Maintaining adequate stream flows is vital for river and riparian ecosystem health as well as highly water-based economic sectors such as agriculture, fisheries, and recreation.*

   a. *If at least 40% of the total annual water runoff must be annually allocated to maintain stream flows, what is the minimum annual stream flow discharge (m^3) for the entire map area?*

   b. *What is the maximum volume of water (m^3) that can be budgeted for other uses?*

Section 3: Allocating Water While Maintaining Streamflow

The table below shows water demands and societal benefits for each type of water user per 5 x 5 km square on the map. Use this information, the calculations you made in the previous section, and the supplemental computer spreadsheet to answer the questions below.

Table 3. Regional Water Demands and Provisions by Land Area.

Land and Water User Type	Water Use (m^3 per 25 km^2)	Provisions (people per 25 km^2)
Residential	3,500,000	1500 people housed
Institutional, Industrial, and Commercial	2,500,000	3000 people employed
Agricultural	24,000,000	1250 people eating local food; 125 people employed

Note that land left undesignated is assumed as open lands, such as county, state, and federal parks, forests, natural reserves, and other managed landscapes.

6) Scenario 1: Self-Sufficient Community

Allocate lands and the remaining water budget to achieve a self-sufficient community that meets all of the following requirements:

1) *everyone living in the map area works or goes to school in the map area,*
2) *everyone consumes only local food grown in the map area, and*
3) *all food grown in the region are sold and consumed in the region.*

Make sure you use the spreadsheet section designated for Question 6.

a. *What is the maximum population that this area can sustain while achieving all requirements? There is one correct answer.*

b. *Fill out the table below based on your spreadsheet land designations for Question 6a.*

Land and Water User Type	**Grid Squares Allocated**	**Total Land Area Allocated (km^2)**	**Total Annual Water Use (m^3)**
Residential			
Institutional, Industrial, and Commercial			
Agricultural			

7) Scenario 2: Global bread basket.

Assume conditions of Scenario 1, except that now 60% of all agricultural products are exported from the region, similar to the San Joaquin Valley of California. Make sure you use the spreadsheet section designated for Question 7.

a. What is the maximum population that this area can sustain while achieving all requirements? There is one correct answer.

b. Fill out the table below based on your spreadsheet land designations for Question 7a.

Allocation User Type	**Grid Squares Allocated**	**Total Land Area Allocated (km^2)**	**Total Annual Water Use (m^3)**
Residential			
Institutional, Industrial, and Commercial			
Agricultural			

Part 4: Additional Exploration

8) Explain at least two assumptions used in this activity. These can be related to land or water usage, food and housing provisions, land use feasibility, on or other components of the exercise.

9) Look at Table 1b and your answers for Questions 1 and 2. Why does annual precipitation vary so greatly across this region of California? This may require some external research.

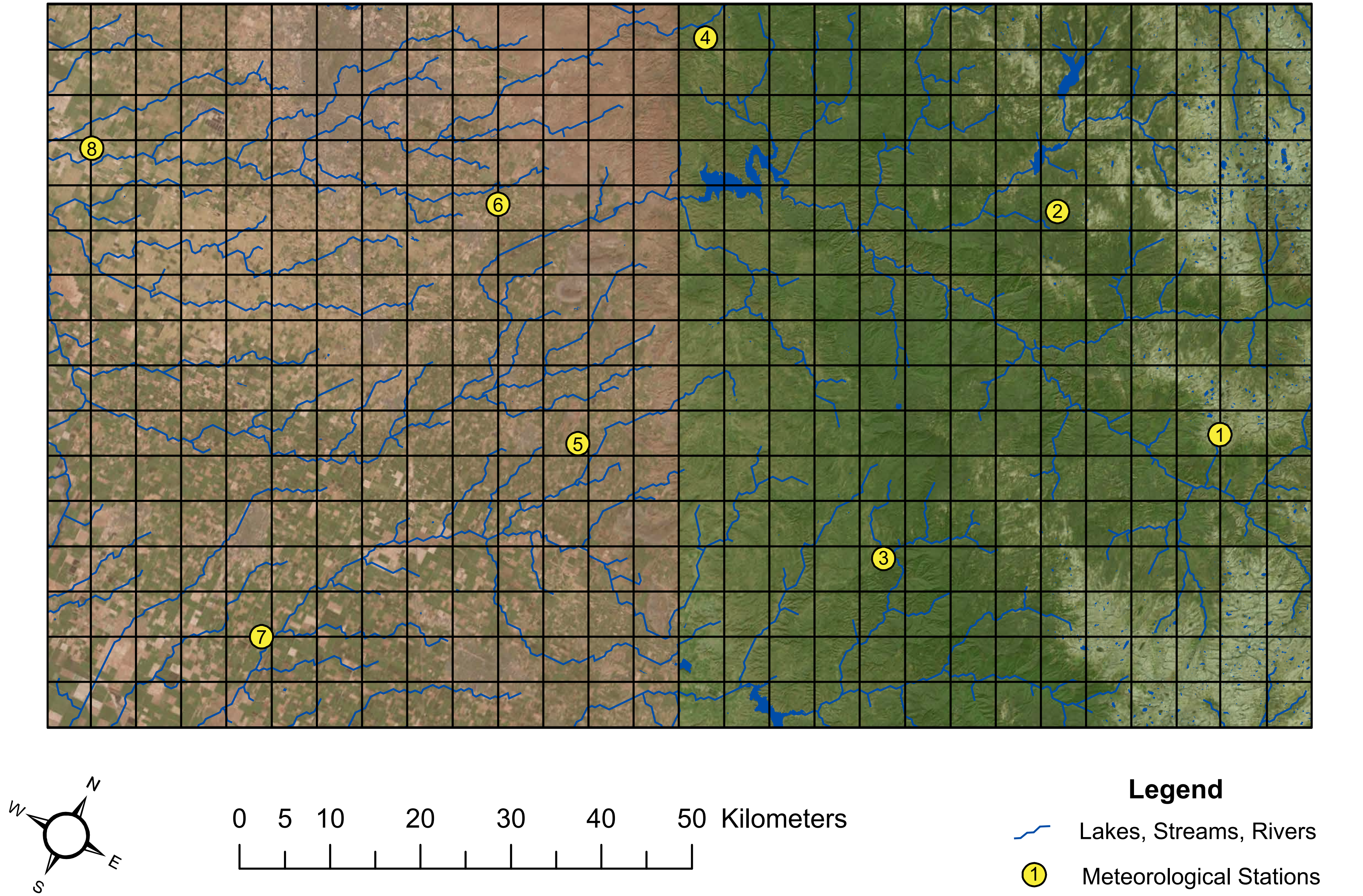
10) How would longer-term changes in water inputs affect water budgeting and infrastructure, for instance during a multi-year drought? What are two management solutions you would recommend to avoid social, economic, and environmental disasters in such conditions?

11) *Consider seasonal changes in water inputs. In a temperate climate, precipitation occurs year-round and generally evenly throughout the year. In a Mediterranean or monsoonal climate, most precipitation occurs at a certain time of year with mostly dry weather the rest of the year. What kinds of infrastructure would be required to support a society in a Mediterranean climate where the precipitation season does not overlap with peak growing season?*

12) *Using Map 2 and colored pencils, design your allocated lands for one of the scenarios in Section 3 and discuss your design below. Consider diverse infrastructure needed in your design, such as irrigation, road construction and maintenance, utility services, etc.*

SimWater: Mountains to Valley

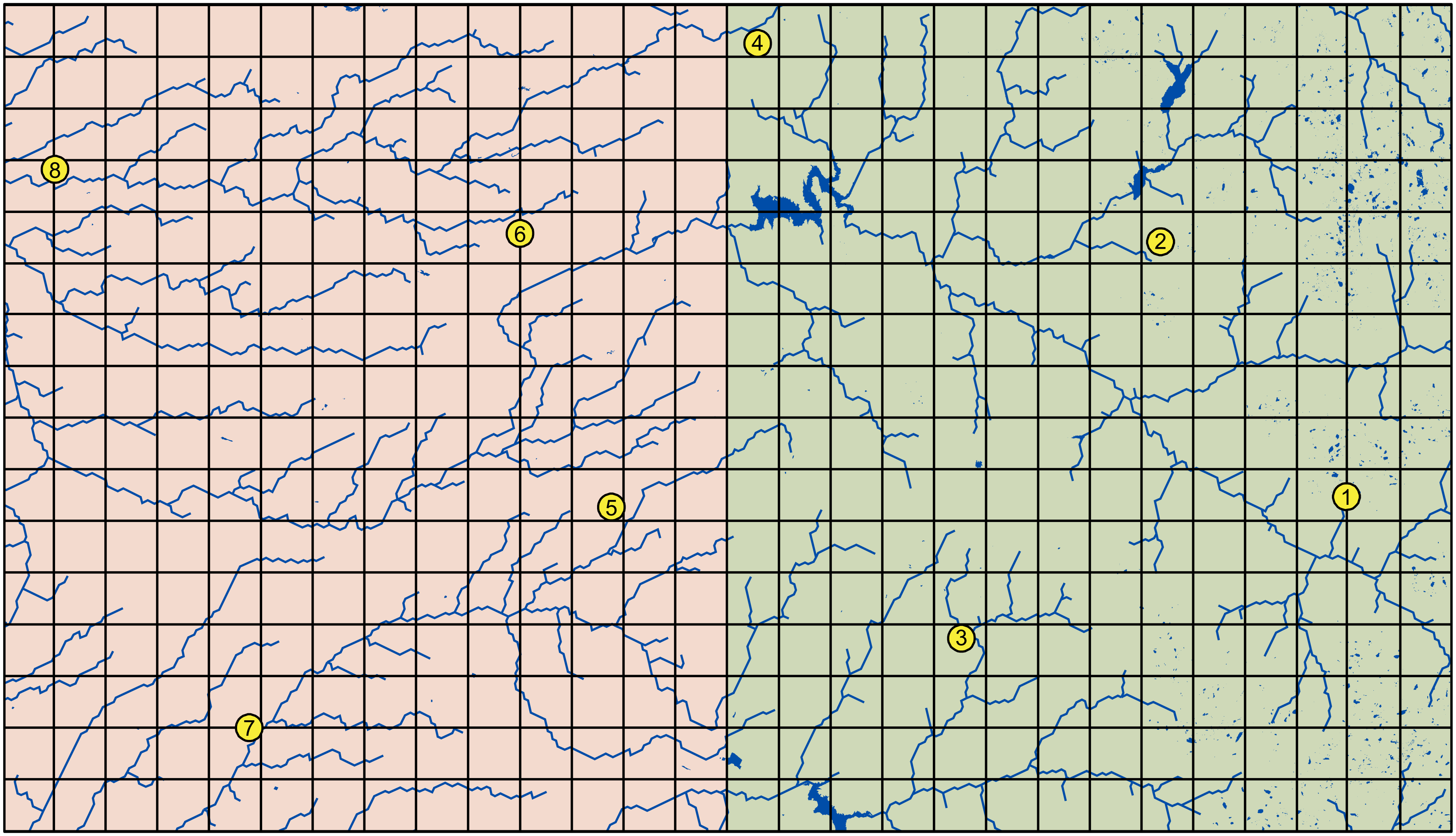
Map 1

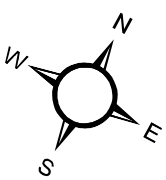


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

SimWater: Mountains to Valley

Map 2





0 5 10 20 30 40 50 Kilometers

Legend

- Lakes, Streams, Rivers
- Meteorological Stations
- Valley
- Mountains

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community