Integrating GIS technology with RiverWare

Functional Requirements

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Graphical information systems (GISs) support storage, analysis, and display of spatial data. While most types of RiverWare objects represent physical objects that are located in space, RiverWare does not represent or make use of information about the spatial extent and location of the modelled objects. This document motivates and describes requirements for the use of GIS technology within RiverWare.

1 High Level Requirements

In this section we provide a brief description of the immediate goals for incorporating GIS technology into RiverWare; in subsequent sections we motivate and describe more detailed requirements. The new functionality will support a map based view of the modelled basin. By providing an intuitive and information-rich view of a basin, the map-based view will complement the existing schematic views.

1.0.1 Support georeferenced objects

RiverWare will support the assocation of *spatial coordinates* with each object. The spatial coordinates for an object will be represented as a pair of floating point numbers, and will be interpreted as either the object's geographic coordinates (latitude and longitude) or cartesian coordinates in a projected coordinate system (easting and northing, or x and y). The user will be able to provide objects with spatial coordinates in the following ways:

- By interactively entering the two numbers.
- Through graphical interaction with the workspace. For example, the user could drag an object from its original location on a map display and drop it at the map location corresponding to its spatial coordinates. Alternatively, the user could select a location on a map display and then indicate which object has that locations as its spatial coordinates.
- From a file in standard GIS format.

  [I recommend that we remove this last bulleted requirement because this represents a significant amount of software effort for little payoff. This is a one-time operation for each model, and I doubt that many of our users would take advantage of this feature.]

1.0.2 Support a geospatial workspace view

In the geospatial workspace view object icons, links, and a background image are displayed in a spatially consistent way. That is, the background image is taken to be a map projection and each object icon is displayed at (or near) the location on this map which corresponds to the object's spatial coordinates.

RiverWare will be able to read and display background maps in standard image and GIS formats. Note that some formats support information about the image's location in a coordinate system, and some do not. Appropriate mechanisms will be provided for user input (and persistence) of this information for images that do not already contain it.

[Are any of our users likely to have images in a GIS format that contains projection information?]

1.0.3 Design for additional integration

Current development should facilitate further integration of GIS technology with RiverWare in the future.

2 Description of the current workspace functionality

In this section we discuss the purposes currently served by the RiverWare workspace, so that we can evaluate how GIS technology might improve or complement this functionality. Note that the main RiverWare dialog provides menu-based access to most RiverWare functionality in addition to providing the workspace display discussed here.

- **Schematic visualization of the modelled river basin**. This display indicates how the basin has been abstracted and discretized by the user into objects, and for each object shows the name, type, and relationships with other objects (i.e., links indicating information sharing between objects).

  In this schematic view, each type of object has a distinct, predefined icon (image) associated with it, each object in the model is represented by an icon of the appropriate type, and each icon is labelled below with the object's name. The user can manually arrange the object icons and the resulting object locations are saved within the model file.

  Links are drawn as lines between icons, and the color and style of these lines can be controlled by the user. Links can be organized into groups.

  Users control the focus of the workspace by scrolling and the level of detail by zooming in and out.

  Two types of schematic views are supported, Simulation and Accounting. The two views are conceptually similar, but the accounting view displays additional object information pertaining to water ownership (e.g., which accounts are associated with an object and what are their types).

  The object icons in each view are different, their locations in each view can be different, and RiverWare makes no assumption about the relationship between an object's location in either view and the object's actual, physical location (if any).
- **Access to more detailed information organized by object**. This information is accessed by double-clicking on the object's icon, and includes object data and methods.
- **Support for model creation**. The user interacts with the workspace to create and locate objects as well as to create links between the objects.
- **Selection of multiple objects**. For actions that operate on a collection of objects, such as creating a subbasin or saving a subset of the objects to a file, the workspace provides a graphical mechanism for defining the collection of objects on which the action will operate.

Each workspace view is drawn on a conceptual "canvas" which is characterized by the following user-settable attributes:

- Size (default width = 6450, height = 6450)
- Background color
- Text color
- Canvas font size

RiverWare 5.1 added support for a background image in the simulation view. Users can specify an image in a standard format and that image is displayed as the background of the simulation view of the workspace. The image file must be in the same directory tree as the model file and its relative path to the model file is retained in the model file. If the background image is a map of the modelled basin, then the user can manually rearrange the object icons to correspond to the actual locations of the associated objects on the map. In other words, the user can use this functionality to create a simulation workspace view in which the schematic view of the model basin is overlayed on top of, and in registry with, a map of the basin.

[See Phil's document "Georeferencing Simulation Objcts in RiverWare: Proposal" for details and limitations of this approach as well as possible extensions.]

3 GIS technology and RiverWare

In this section, we briefly discuss GIS technology and suggest ways in which RiverWare might usefully access this functionality.

3.1 Coordinate systems and projections

This section introduces some basic GIS terminology and concepts.

Locations on the earth are most often represented as a pair of coordinates representing latitude and longitude. For some applications, a third coordinate representing something like elevation relative to mean sea level is also used. Apart from this spherical coordinate system, GIS systems typically represent locations as cartesian coordinates in a plane onto which the surface of the globe has been projected.

Several standards have been developed to provide agreed-upon coordinate systems for a given area. These standard coordinate systems define a set of map projections with together cover the target area. One common coordinate system which covers the globe is the Universal Tranverse Mercator (UTM) coordinate system. This system defines a projection for the northern and southern areas of each of 60 longitudinal zones spanning the globe. For example, in the projection UTM Zone 11 North, the coordinates eastings = 397,800 m, northings = 4,922,900 m, corresponds to a location in central Oregon.

Another standard coordinate system is the State Plane coordinate system which defines a set of projections for the United States. In this system, each state is divided into one or more zones, so a location is specified by a state, zone designation, and x, y coordinates.

Note that a standard coordinate system defines a mathematical coordinate system corresponding to each projection; when these two uses of the term "coordinate system" would be confusing, we use the the term to refer to the standard, and use the term "projection" or "map projection" for the component coordinate systems.

Coordinates, whether they be geographic (latitude and longitude) or correspond to a map projection, are specific to a datum. A datum is a reference surface and surveyed coordinates for a set of actual points and lines. Examples of common datums include the North American Datum of 1983 (NAD83) and the World Geodetic System of 1984 (WGS84).

From "GIS Fundamentals" (Bolstad, 2008):

> Exact or approximate mathematical formulas have been developed to convert to and from geographic (latitude and longitude) to all commonly used coordinate projections. These formulas are incorporated into "coordinate calculator" software packages, and are also integrated into most GIS software. For example, given a coordinate pair in the State Plane system, you may calculate the corresponding geographic coordinates. You may then apply a formula that converts geographic coordinates to UTM coordinates for a specific zone using another set of equations. Since

> the backward and forward projections from geographic to projected coordinate systems are known, we may convert among most coordinate systems by passing through a geographic system.

That is, it is relatively easy to convert back and forth between geographic coordinates and coordinates from a known projection; whereas a method for direct conversion between two different projections is not generally available.

3.2 Display

While GIS applications usually support tabular displays of data, the spatial aspect of the data allow it to be organized visually by geospatial location. Thus a primary feature of most GIS applications is the visual rendering of spatial data, i.e., the drawing of maps.

Displays can be very flexible, allowing user control over both which data are displayed at any given moment as well how those data are displayed. The data and display are typically organized into layers, and the user might have control over the following aspects of the display:

- Whether or not each layer is visible and with what level of transparency.
- How the data associated with a layer is visualized, e.g., for raster elevation data, is a contour plot drawn or are the elevations indicated on a per cell basis using a grey scale.
- Whether or not icons are associated with data, which icons and how they are presented (e.g., size, color, and orientation to the datum's coordinates).
- Whether or not labels are present, the label font, orientation, etc.
- Whether or not a legend is drawn and its appearance.

Stand-alone GIS applications can be very sophisticated in their displays, especially in how they deal with zooming in and out. For example, at different levels of resolution, an application might automatically change font size and move or omit labels.

Note that the GIS data and maps can be displayed on a screen or saved to a file. Output formats vary greatly in the degree to which the structure of the original information is retained as well as with respect to which other applications are likely to be able to understand and display files in that format. For example, the ESRI shape file format is supported by most GIS applications and allows retention of the original structure of the data. By contrast, the JPEG image format, while supported by many applications that display images, does not retain any spatial information or even the structure to allow, for example, toggling of the layers used to generate the image.

The following list enumerates some of the ways in which RiverWare could support the display of spatial data, listed in order of increasing sophistication and flexibility:

1. Display a single background image without knowledge of its projection. This functionality is currently supported for the simulation view, and permits the display of a schematic view overlayed in registry with a map.
2. Display a single background map image with a known location in a coordinate system. Coupled with georeferencing for objects where the spatial coordinates are from the same projection as the map image, this option supports the display of a schematic view overlayed in registry with a map, and adds the ability to be change the background image to another one from the same projection without needing to change the spatial locations of the objects. In this scenario, RiverWare asumes that the spatial coordinates and background image(s) are from the same projection, but RiverWare does not need to know anything about that projection.

   [I think this is the option proposed in Phil's document.]

3. Display a single background image with a known projection and location in that projection. This is like te previous option, except that it relaxes the requirement that the spatial locations and map images each come from the same projection. In this option, RiverWare knows the projection for each image as well as for the objects' spatial locations and makes the appropriate transformations to display them in a single display.
4. Display of layers, each of which consists of either a map or a collection of RiverWare icons. This is a variation of (2) or (3) in which adds the ability to organize the view into layers, permitting interactive control over aspects of each layers display (e.g., which layers are displayed).
5. Display of layers, with each of which is associated a spatial data set or a set of RiverWare objects. The user has control over how each spatial data set is visualized (rendered), e.g., what icons are used, how labels appear, etc. In other words, this option would provide the full power and flexibility of GIS visualization within RiverWare.

3.3 Analysis

Analysis of spatial data has many application to water resources modelling. For example, contour information in the fom of digital elevation maps (DEMs) can be used to compute direction of stream flow, determine upstream/downstream relationships between reservoirs, compute rainflow runoff, or delineate catchments. The ability to perform, or import the results of, these and similar analyses could be useful within RiverWare.

3.4 Data access

Spatial databases employ both vector and raster representations of spatial data, and support the association of attributes (non-spatial data) with each datum. Most spatial data are stored and shared in one of a small number of formats (e.g., USGS DLG format, ESRI shape file format).

To the extent that the attributes and object abstractions represented within a spatial database match those required by a RiverWare model, that database could be used to help provide information to a RiverWare model. For example, a GIS database might contain representations of reservoirs in a basin with attributes which include the reservoir name. RiverWare could use such a database to provide objects with their spatial coordinates for the geospatial workspace view, as well as to initialize other modelled object attributes. RiverWare's namemap capability could be used to facilitate access to this information by relaxing the requirement that names in the database match those in the RiverWare model.

Current RiverWare DMI functionality allows RiverWare to access series data in spatial databases, though we could consider creating new direct database connections for specific database formats.

4 High level software architecture

To integrate GIS functionality with RiverWare, we might want to apply one or more of the following software approaches.

- Homegrown - we write code to do what needs to be done. This is what Riverside Technology did for their StateMod application.
- Link to a GIS library - link RiverWare to a 3rd party library with a C++ API that provides the desired functionality.
- Implement a GIS plugin - Create a GIS plugin to support the new functionality, possibly using a 3rd party GIS library.

- Add RiverWare as a “plug-in” or customization of an existing GIS stand-alone tool - This is what DHI did for their Mike Basin application (using the ArvView GIS application).
- Communicate in real time with a GIS application. Spatial databases might be accessed via DMIs, or in the future perhaps as a web service.

5 Open source GIS software

The following are open source GIS packages that are available on at least the Windows and Linux platforms. Many other GIS packages are more restrictive, for example, Idrisi and MapWindow are supported on Windows only, and GeoVISTA Studio consists of Java bean components.

- GRASS: Open source C stand-alone GIS application and library, supported on Window/Linux. GRASS/Qt is a library for accessing GRASS functionality from Qt developed and made available as open source by Navicon.
- Quantum GIS (QGIS): Open source stand-alone GIS application and library, supported on Window/Linux/others, uses Qt4. Documentation contains an example of accessing QGIS from other applications. From the documentation: “Required dependencies of Quantum GIS include GEOS and SQLite. GDAL, GRASS GIS, PostGIS, and PostgreSQL are also recommended.”
- GDAL/OGR: Open source C++ libary for reading/writing various formats (the GDAL library supports raster formats, OGR supports vector formats).

6 Notes

The existing schematic views will always be useful, but we might want to consider modification to the schematic “overlay” in the geospatial view. One can imagine situations in which the user would not want to see the schematic view at all, or see the icons differently. For example, they might want to view objects as labelled dots instead of the standard icons, letting the background image remain unobscured. Tool tips or selection in a geospatial view could be sufficient to indicate the underlying RiverWare objects.

How should we deal with objects that do not have spatial coordinates, including all objects of type DataObj and ThermalObj? Note that DataObj’s are in practice often associated with actual physical objects (e.g., each reservoir object in a model might also have an associated DataObj.

While RiverWare should be flexible with respect to scale, there is a range of scales which are more likely to be of interest at the basin level (e.g., maps with a 1:240,000,000 scale would likely not be very useful). Does this have any implications for the current design?

Consider relevance of the Spatial Data Transfer Standard, a standard developed by the USGS used to describe earth-referenced spatial data, designed to support transfer and use spatial data on different computer platforms.

Do we need to provide a mechanism to document the datum associated with spatial data?

Initially we are representing the spatial extent of RiverWare objects as points, but in the future we might want to additionally support line and area vector representations (typically represented in GIS systems as sets of connected line segments and polygons respectively). How should we design for this potential future enhancement? What functionality might the more general representation support? Note that the actual visualization (rendering) of spatial data is probably something that we would want to farm out to 3rd party software. On the other hand, being able to answer a question like “With which object(s) is the given coordinate on the geospatial workspace view associated?” might be useful and might require access to a more sophisticated object representation.

One issue: how much does RiverWare need to know about the map projection of an image or spatial coordinates? There are some many possible projections, we don’t want to require any sort of structured knowledge of the possible projections be contained within RiverWare, but it is possible to access this sort of knowledge in a third party library. For example, we probably don’t want to create an interface in RiverWarethat knows that UTM has three components, what they are, etc..