Towards an Open and Integrated Cyberinfrastructure for River Morphology Research in the Big Data Era

Venkatesh Merwade[1], Ibrahim Demir[2,3], Marian Muste[3], Amanda L. Cox[4], J. Toby Minear[5], Yusuf Sermet[3], Sayan Dey[4], Chung-Yuan Liang[1]

[1] Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47906
[2] Civil and Environmental Engineering, University of Iowa, Iowa City, IA, 52246
[3] IIHR-Hydroscience & Engineering, University of Iowa, Iowa City, IA 52242
[4] WATER Institute, Saint Louis University, St. Louis, MO 63103
[5] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309

Abstract

The objective of this paper is to present the initial illustration of a cyberinfrastructure named the River MORPhology Information System (RIMORPHIS) that addresses the current limitations related to river morphology data and tools. A new specification for data and semantics on river morphology datasets has been developed to support the web-based platform for discovering and visualization of river morphology data. Several geoprocessing tools are developed that enable scientific analysis and practical studies, including the coordinate transformation, cross-section generation and bathymetry mesh generation. Our vision for RIMORPHIS is to create a self-sustained community platform with tools to support scientific discoveries on river morphology and to enable multidisciplinary research for riverine environments. To accomplish this vision, we created a community to gather input and build partnerships. The RIMORPHIS cyberinfrastructure addresses the community needs related to data access, processing, and visualization. The current implementation of RIMORPHIS is scalable for new data and tools.

Keywords: river morphology, information system, cyberinfrastructure, data discovery and access

Highlights

- A prototype River Morphology Information System is created.
- RIMORPHIS enables data discovery, access and processing related to river morphology data.
- RIMORPHIS tools include coordinate transformation, cross-section generation and bathymetry mesh generation.

1. Introduction

Rivers and streams are increasingly recognized for their importance in understanding the water cycle (Carpenter et al., 2011), aquatic biogeochemistry (Butman and Raymond, 2011; Raymond et al., 2013), and of the exchanges with groundwater and hyporheic zones (Boulton et al., 1998) from local to global scales. Once thought of as inactive pipes benignly transporting water and constituents from one place to another, rivers are now seen as dynamic environments where major interactions and alterations occur (Butman and Raymond, 2011). Given that human populations rely heavily on rivers for essential services, including municipal and agricultural water supply, hydropower, and flood protection, inland waterways are among the most heavily human-altered of all ecosystems, with human-caused changes to morphology (damming, diking), hydrology (quantity, quality, temperature, timing), and biogeochemistry (excess nutrients, toxic substances) (Carpenter et al., 2011).

Despite their significance to our populations, we have remarkably limited knowledge about rivers, including their morphological aspects and evolution over spatio-temporal scales (Biancamaria et al., 2016). For example, in the United States, one of the most well-studied countries in the world, river bathymetry remains one of the least measured land features (U.S. Geological Survey, 2019). This data gap has large consequences in areas like flood protection (Alabbad and Demir, 2022) and forecasting (Sit et al., 2021a) where recent studies have found that outdated flood inundation maps in the US underpredicted flood risk nationally by 260-310% (Wing et al., 2018) with a 1% chance of annual damages exceeding $78 billion (Quinn et al., 2019). The major limitations identified in these studies are the lack of river bathymetry and understanding of river changes over time.

River morphology data, including river centerline, bank lines, bathymetry, and bed and bank material composition, are critical for studying and understanding aquatic processes, including hydrodynamics, sediment transport, nutrient transport, and fish habitat. An assessment of the current state of river morphology data in the US highlights several critical issues. First, there is a lack of easy access to river morphology data and a place to store, publish, and share these data with the broader earth sciences community. For example, except the river centerline, most river morphology data are rarely available in the public domain. Even river reach data, for example in the National Hydrography Dataset (NHD), do not accurately provide the actual river centerline for most streams.

The NHD High Resolution (NHD HR) data do incorporate locally created information, including streamlines derived from Light Detection and Ranging (lidar), but these data still do not include river bathymetry or bank lines. Data on river bathymetry and other morphological features are commonly collected locally through ground surveys with total stations in wadeable streams, or Global Positioning System (GPS) equipped boat mounted surveying techniques in deep streams (Allouis et al., 2010; Bangen et al., 2014; Hostache et al., 2015). These data are collected and stored either as cross-sectional surveys (linear features) or a set of points. Additionally, the data can take up significant storage space (especially for new technologies such as multi-beam echosounders), thus hindering easy sharing with the broader community.

The second issue with river morphology data is their availability over large areas within a stream network. While locally collected river morphology data can provide information at high spatial resolution (i.e., from a few centimeters to several kilometers), these data cannot be continuously collected over large areas. For example, local bathymetry data collection methods using boat-mounted techniques cannot be used for an entire stream network due to logistics, cost, and safety considerations (Casas et al., 2006; McKean et al., 2009; Allouis et al., 2010; McKean et al., 2014). On the other hand, large-scale bathymetry data collection methods, including the bathymetric lidar and spectral photogrammetry, cannot be applied to deep, turbid, and turbulent rivers (Kinzel et al., 2007; Feurer et al., 2008; Legleiter and Overstreet, 2012; Kinzel et al., 2013; Legleiter, 2014; Pan et al., 2015). Thus, river morphology data are typically limited to small areas of locally measured data that are sparsely spaced over a stream network of a basin.

The third issue with river morphology data is the absence of processing tools that can enable the use of these data for specific scientific and practical applications. Despite spending considerable resources to collect local river morphology data, most often the data are not available in a form that meets the needs of a specific project. For example, river bathymetry data collected using a boat-mounted sounder cannot be directly used to construct a one-dimensional hydraulic model that requires riverbed information in the form of cross-section cut lines. Similarly, very dense high-resolution bathymetry datasets collected using multi-beam echosounders can add unnecessary computational burdens to studies requiring lower resolution data. Thus, there is a need to process locally collected river morphology data before it can be used effectively. Some tools are available, including RiverSurveyor (SonTek, 2018) and HYPACK (McKean et al., 2009), but many of these work with proprietary software and are not easily accessible to the broader community.

Finally, the fourth issue deals with the need to create and host tools that take advantage of locally collected river morphology data to advance the science and engineering of river morphology (Collins et al., 2012). Multiple tools exist in literature (Zahiri and Dehghani, 2009; Goldstein et al., 2019), but the ability to easily and publicly access and use these tools is lacking. Can tools be developed and disseminated to leverage the existing data for extracting key river characteristics (e.g., river bathymetry) over large spatial domains to understand and solve river morphology issues that are currently unsolvable due to data constraints? With the accumulation of accessible, reliable, and sustainable data, data-driven models promise to enable extraction of insights, predictions, or quantitative relationships from large, multi-dimensional datasets using automated tools (Anderson, 2008; Hey et al., 2009). Also, the development and hosting of data-driven tools, such as machine learning (Xiang et al., 2021) and real-time modeling (Li and Demir, 2022) and data analytics tools (Sit et al., 2021b), can advance the science of river morphology and watershed studies.

The need to address the above issues can only be attained if the data science supporting the investigations of river morphology, hydrodynamics and other related processes can be substantially advanced. Considering the importance of rivers in the overall hydrologic system, justifying how such data and related tools will help improve our understanding of rivers and their impact on hydrology is also important (Church, 2013; Piégay et al., 2015, Xu et al., 2019). For example, the National Water Model from the National Weather Service in the US provides near real-time flow and flood inundation forecasts for nearly 2.7 million stream reaches in the United States using the National Elevation Dataset (NED), but the NED does not accurately capture the river location, including the bathymetry. The question then is how are these forecasts affected by not having accurate river morphology? Similarly, many physical processes within a river ecosystem are affected by the interaction of a river and its floodplain. How is our understanding of these interactions dependent on the accurate description of river morphology? Answering these and other questions related to rivers and their interaction with our built infrastructure and society will require river morphology data and tools to process these data.

The objective of this paper is to present a prototype river morphology platform, named the River Morphology Information System (RIMORPHIS), that addresses the issues identified earlier related to river morphology data and tools, and to illustrate initial developments of the RIMORPHIS prototype. The prototype is designed to be scalable, extensible and interoperable. The vision for RIMORPHIS is first presented in the next section including the underlying conceptual framework and strategies for its broader implementation. Given that RIMORPHIS is built with and for the broad communities of Earth Science and practice, the subsequent section describes the overall strategy to engage with these communities and the practical steps for strategy implementation. This is followed by the description of the prototype and illustration of RIMORPHIS workflows that can be used to address issues related to data access, processing, and river morphology research.

2. RIMORPHIS Vision

The overall vision for RIMORPHIS is to create a self-sustained community platform with tools to support scientific discoveries on river morphology and to enable integrated multidisciplinary research for riverine environments. The scope of the platform is commensurate with the increasingly complex issues of riverine systems resulting from the multiple competing stresses applied to river environments. Consequently, the platform can be linked to comprehensive multi-disciplinary river morphology data resources aligned with contemporary priorities in geoscience research. RIMORPHIS is a user-friendly, scalable, data and information system for river morphology research, equipped with tools for discovery, retrieval, analysis, integration, and knowledge generation. Given its community focus, RIMORPHIS includes visualization and collaboration tools that enable transparency and reproducible research outcomes.

The overall conceptual architecture of RIMORPHIS and its components are shown in Figure 1. RIMORPHIS connects all data and information through a framework that uses the river network as the skeleton. Within this framework, cross-sections, or collection of points along a cross-section are connected to a reach which is then connected to a stream network within a watershed. This framework enables seamless integration of datasets irrespective of their location and timeframe, and also enables building of customized applications utilizing the data for routine management operations or exploratory scientific investigations.

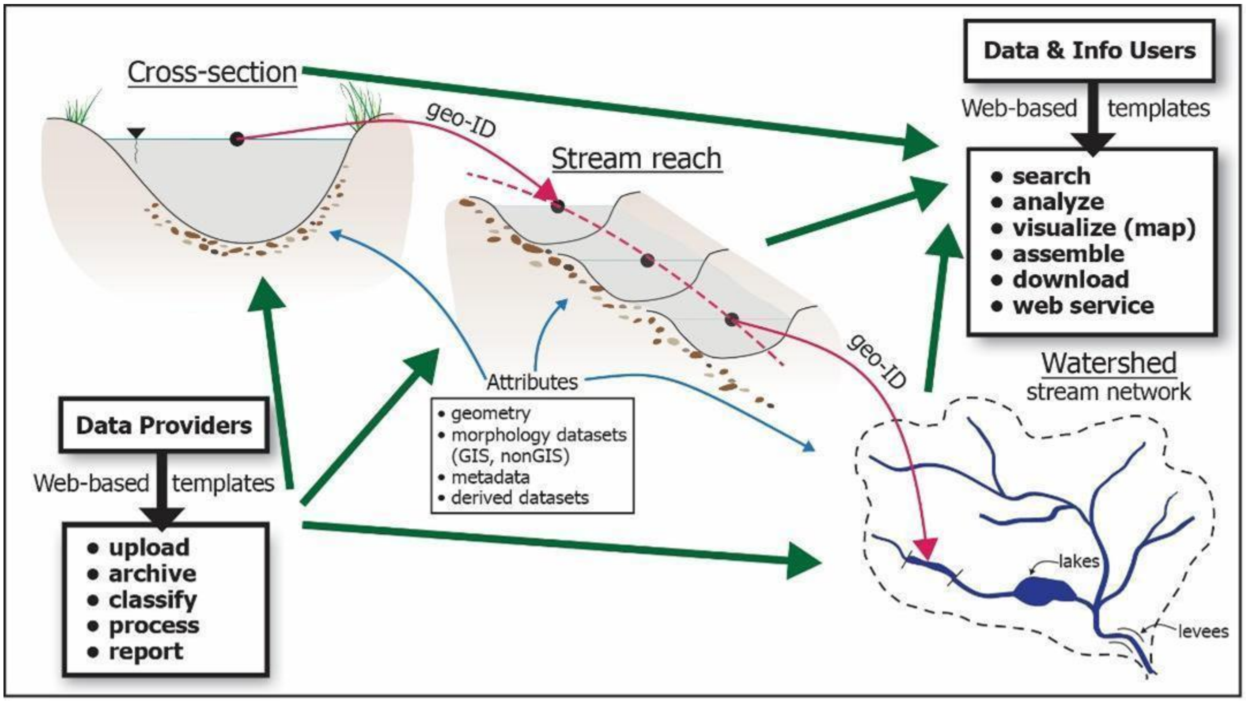


Figure 1. RIMORPHIS architecture illustrating elements to be included in the design specifications (database structure, dataset types and formats, metadata, geospatial links, operational and functional features)

Table 1. Parameters and their descriptions guiding RIMORPHIS design

Parameters	**Description**
Scope	What data, processes, and features should be supported?
Scale and scalability	How to enable broad, trans-boundary integration of heterogeneous data for local to national scale analyses? How can RIMORPHIS be scaled from relatively few users in the beginning to a larger number of users across multiple disciplines within geosciences?
Functions	What metadata should be associated with the data? Will the database be able to store calculated data?
Operation	Who will provide quality assurance? What tools and workflows will be associated with the RIMORPHIS for data discovery, visualization, retrieval, and sharing?
Management	What are the protocols for accessing and protecting data, maintaining the system, and updating computer/communication technologies? Who will manage and administer the database after its development?
Sustainability	How might data collectors be encouraged to make the additional effort to submit their data to RIMORPHIS. Who, ultimately, will host and maintain the database and thus provide adequate resources to sustain it?

Implementation	What is the most efficient strategy to connect and integrate the existing databases and tools? What are the new features that need to be added to attain a customized but generalizable data model with imported features?

In order to fulfill the RIMORPHIS vision, its design is guided by several parameters presented in Table 1. The current version of RIMORPHIS does not address all these aspects, but development of the database, backend infrastructure, tools and functionalities are guided by these principles as they are related to any specific component.

3. Community Engagement

RIMORPHIS is envisioned as a community cyberinfrastructure, and accordingly it is critical to set a general strategy and adequate tactics to engage with a large number of data providers and users across multi-institutional settings. These engagements are enabled through in-person and virtual workshops. Furthermore, the design and actual development of the platform is best accomplished with, and for the benefit of, the members of the geomorphologic science and practice communities. Engaging with scientists and researchers from diverse, multi-institutional science and practice communities within the Earth Sciences area requires strategies distinct from those geared for engagement with stakeholders or public communities (e.g., Wellcome, 2011). There are few models available to inform on strategies for engaging communities of scientists and researchers with the community of practice (e.g., CSCCE, 2022; WHONDRS, 2022). Combining the best available information and our own experience led to the strategy for community engagement and collaboration illustrated in Figure 2.

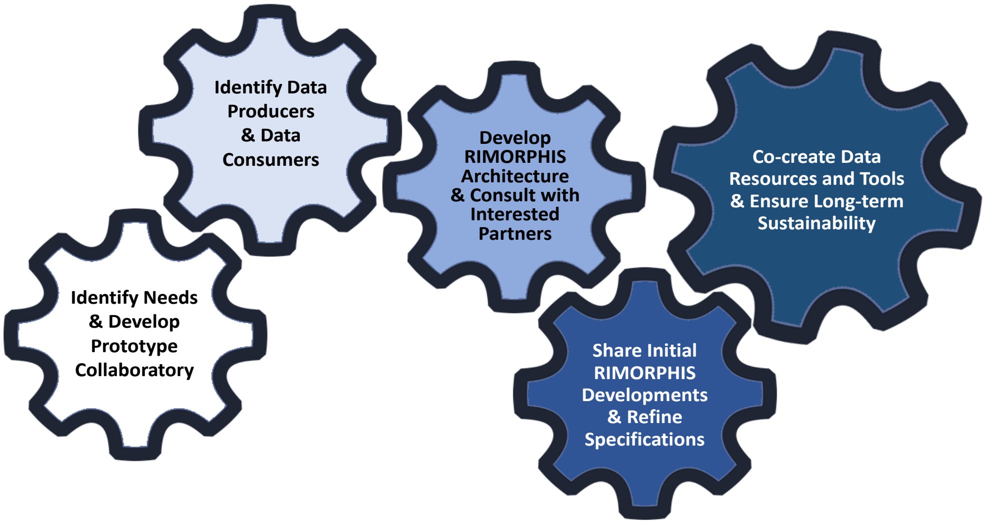


Figure 2. RIMORPHIS community engagement and participation phases

The community engagement strategy adopted for developing and ensuring long-term sustainability of the platform is described in more details in Cox et al., 2024. Specifically, the broader community was engaged in the development of the conceptual architecture and the data resources production process leading to an operational platform. In the first phase of the engagement efforts, we identified and screened potential collaborators, starting with the national data producers that have the most advanced platforms for data access and a sizable amount of data to share. During this phase, we started one-on-one in-depth data sharing discussions with the following data providers: the US Army Corps of Engineers' (USACE) Hydrographic Survey (eHydro), USACE's Interagency Geomorphic Data Exchange Portal (DGEP), and the US Geological Survey's (USGS) 3D Elevation Program (3DEP). This led to finalizing the preliminary data sources that RIMORPHIS can support and the tools needed to operate on these data. Community engagement is also needed to develop a business model for the sustainability of the platform.

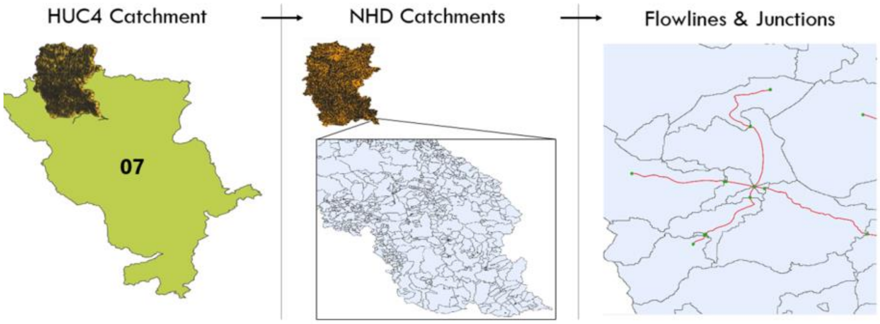
4. Cyberinfrastructure Development

Based on the functional and operational aspects outlined in the RIMORPHIS Vision Section, a prototype RIMORPHIS platform has been developed to address the issues discussed in the Introduction Section to integrate river morphology data to facilitate river morphology analysis and research. The core functionality and capabilities of the system include the following: a) a new specification for data and semantics on river morphology datasets, b) web-based cyberinfrastructure for information sharing and communication of river morphology datasets, including advanced visualization and filtering tools based on a relational database; and c) data analytics component for modeling and analysis to support test cases from a multi-stakeholder context. Recent community-wide calls have emphasized the need to implement information and communication technologies to advance environmental and geo-science research (Ebert-Uphoff et al., 2017). Data in natural sciences are often high-dimensional, making it difficult to understand and extract useful patterns (Demir et al., 2015). One approach to facilitate understanding is to enable visual insights into the analyzed datasets. Environmental data and information visualizations allow users to comprehend and extract information for upcoming investigations from multi-dimensional datasets through graphic and interactive representations (Demir and Beck, 2009, Sermet and Demir, 2022).

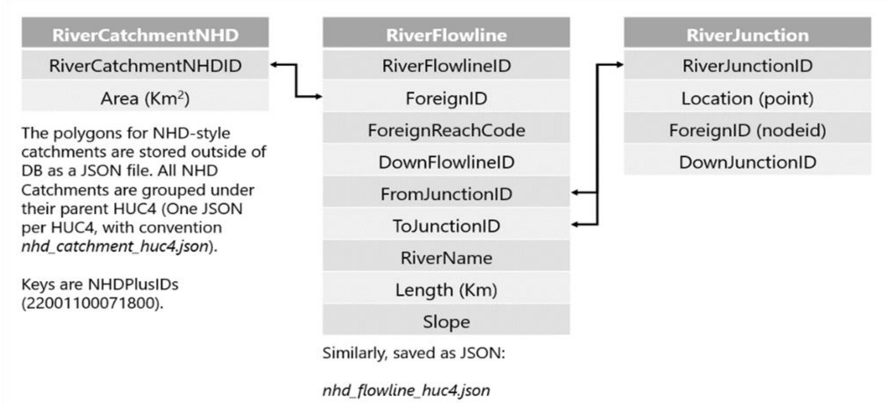
4.1. Data Specifications and Semantics

The prototype RIMORPHIS system stores river bathymetry data in the form of points and lines, but it can be extended to store reach-scale data related to hydrodynamics and sediment. A river morphology data specification was designed to efficiently store, manage, and deliver data at different regional levels (county, sub-watershed, watershed) regardless of the primary source to ensure interoperability as well as suitability for use in interactive web applications. Distributed and scattered bathymetry-related data resources are gathered and indexed to be served via an interconnected database model that is compatible with a variety of data structures from different organizations and individuals with heterogeneous entity identification and relationships in the external data resources. In order to establish a national watershed reference system to associate gathered bathymetry data in their geographical area, NHDPlus High Resolution (HR) is utilized to retrieve catchment, flowline, and junction information for the United States (Figure 3a).

Association of localized river morphology data (e.g., processed river cross-section points) with a national reference system enables complex and large watershed level queries for holistic assessments through the platform. In alignment with this vision, RIMORPHIS has adopted and harmonized existing data specifications from initial partner groups including USACE’s eHydro and USGS’ Topobathy datasets. USACE Hydrographic Survey database (i.e. eHydro) is integrated into RIMORPHIS in a way that the data are retrieved on-demand, for users to visualize available surveys on the map, visualize the raw survey data, process the data with geospatial analytics tools provided within the platform in real time, and interact with 3D models of processed bathymetry datasets.



‘(a) National Hydrograph Dataset referencing system



The polygons for NHD-style catchments are stored outside of DB as a JSON file. All NHD Catchments are grouped under their parent HUC4 (One JSON per HUC4, with convention *nhd_catchment_huc4.json*).

Keys are NHDPlusIDs (22001100071800).

Similarly, saved as JSON:

nhd_flowline_huc4.json

(b) Snapshot of one of the componets of the RIMOPRHIS Data Model

Figure 3. RIMOPRPHIS data model and referencing based on NHDPlus HR

A river morphology database and web service were developed as a publicly available, relational database integrating metadata for the initial datasets (Figure 3b). RIMORPHIS uses a relational database (i.e., PostgreSQL) to store spatial data optimized for web-access and advanced data analytics. A web service API was also developed for community and interoperability. The web service API is used to query the data catalog (metadata), support data access (download), and integrate data into partnering systems (i.e., HydroShare). The data format specification supports many output formats including but not limited to JSON, XML, and CSV. Metadata specifications were created for sharing and cataloging purposes. The API furthermore provides access to chain-like querying mechanisms to filter and join existing data as well as access to bathymetry tools for use by community users in their existing ecosystems and data.

RIMORPHIS stores and handles geospatial layers on an NGINX Server with a POSTGIS-enabled PostgreSQL database and uses the beta channel of Google Maps JavaScript API (application programming interface) for interactive visualization. The prototype involves new visualization and communication tools using JavaScript, Canvas, and WebGL to enable the integration of additional data and model products, visualization of continuous and historical model runs, as well as real-time and ad-hoc data streams. WebGL library allows utilizing GPU directly from web systems to handle and visualize large-scale datasets with parallel computation capabilities. The RIMORPHIS cyberinfrastructure has been designed to produce consistent morphologic data services and information that are published uniformly, stored as needed, and that can be accessed through ubiquitous web interfaces making the system transparent and attractive for collaboration among data contributors. Figure 4 shows a screenshot of a user query to get data from eHydro and create a 3D visualization in the form of a mesh. A user can download these processed data in the format of their choice, including shapefile, GeoJSON or xyz text file.

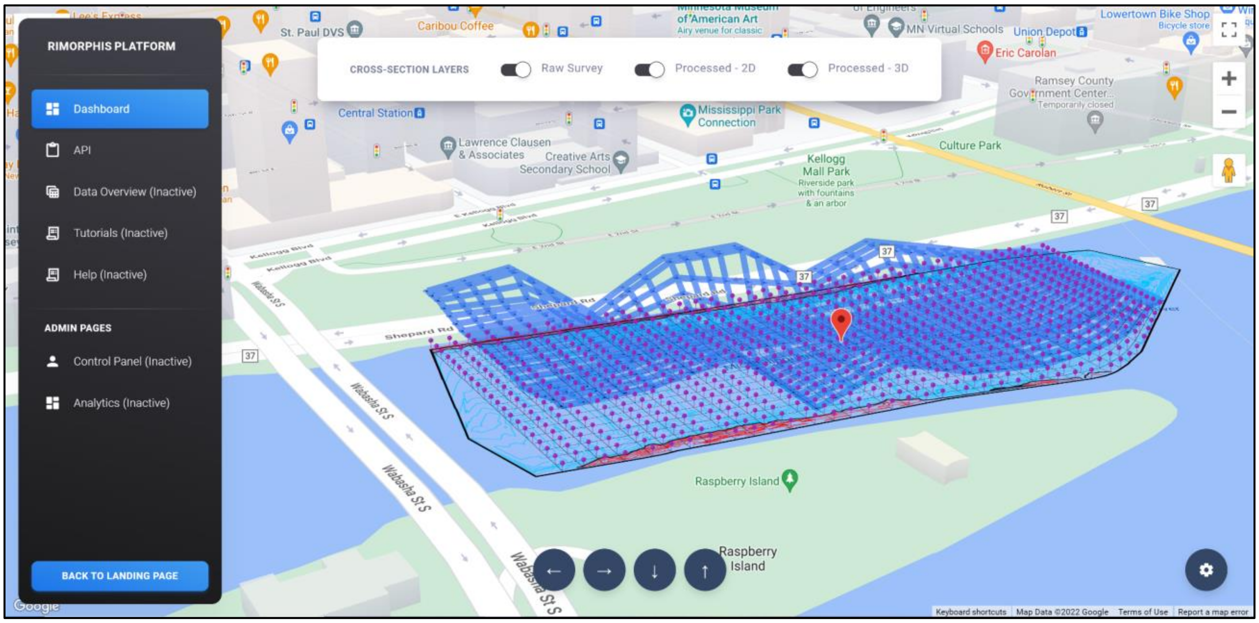


Figure 4. Screenshot from the RIMORPHIS platform showcasing the user interface and interpretable bathymetry visualizations.

5. Geoprocessing Tools and Data Integration

A brief overview of geoprocessing tools and data functionalities within RIMORPIS for accessing data from public resources, processing these data to convert them into usable form and format, and downloading is provided below.

5.1. Bathymetry Data Integration

The USACE is responsible for maintaining thousands of miles of river channels for navigation and hundreds of ports and harbors throughout the United States. Maintaining these waterways requires extensive hydrographic surveying, including bathymetry data collection using single and multi-beam echosounders. The USACE Hydrographic Surveys (eHydro) database includes bathymetry survey data uploaded by USACE Districts (Niles, 2013). eHydro has a map interface where a user can zoom to the area of interest and download available data. The eHydro map interface only shows the location of the survey and does not display the data available. As a result, a user must download the data to assess its usability.

Additionally, the data are available only as a compressed file (i.e., ZIP), which includes information in different formats (e.g., GDB, PDF, XYZ) and a Survey Channel Condition Report (SCCR). As one can imagine, zip files containing data in disparate formats and sizes (in gigabytes) cannot be easily used without a lot of pre-processing, which may not be possible without access to appropriate tools. Finding the appropriate tools for processing river bathymetry data is also a major concern as discussed in the Introduction Section. RIMORPHIS, through its map interface, can access and display locations of all eHydro surveys. Upon request, it can access all the relevant information, such as bathymetry (x,y) points, depths and water surface elevations, convert them to a UTM zone projection and plot them on the RIMORPHIS platform. A chart of this workflow and the result is shown in Figure 5.

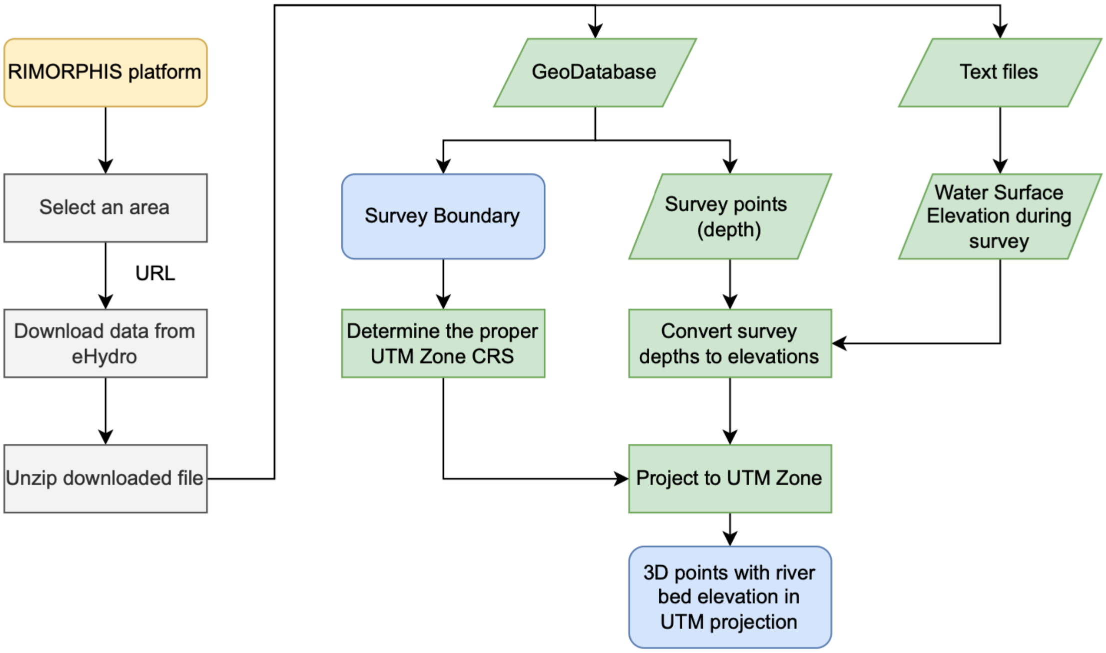
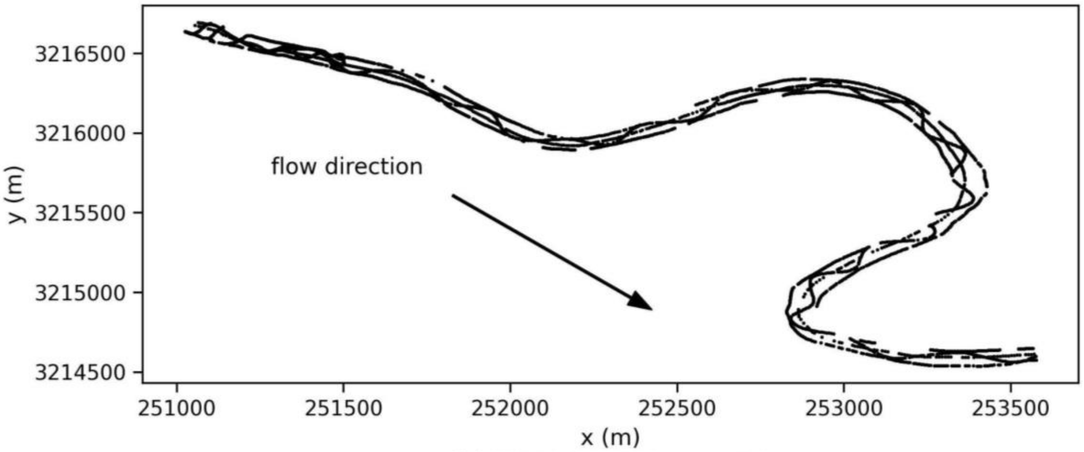


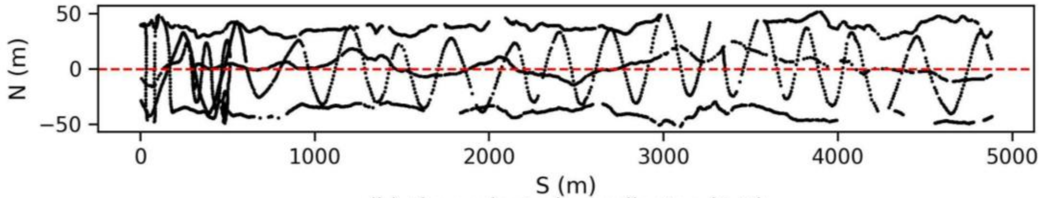
Figure 5. The flowchart of accessing bathymetry data from eHydro

5.2. Transformation From Cartesian to Channel Fitted Coordinate System

Investigating and understanding of river morphologic and hydrodynamic processes require the analysis of field data along and across the flow direction. The data, however, are collected using cartesian (x,y) coordinates which do not account for river flow direction. Thus, most often these data need to be converted to flow-oriented (s,n) coordinates, where s is the distance along the channel centerline and n is the distance across the channel centerline (Merwade et al, 2005). Some tools do exist (e.g., Dey (2019) and Routing Tool in ArcGIS pro 3.0 (ESRI, 2022)), but they are platform and/or software dependent, which requires proprietary software for their use. RIMORPHIS performs this coordinate transformation (Figure 6) as the first step on all bathymetry data after projection. Since the transformation is based on the channel centerline, the user can upload this dataset or RIMORPHIS can use NHD+, which is integrated within the platform. The transformed coordinates are stored as attributes in the bathymetry layer.



(a) WGS 84 / UTM zone 15N



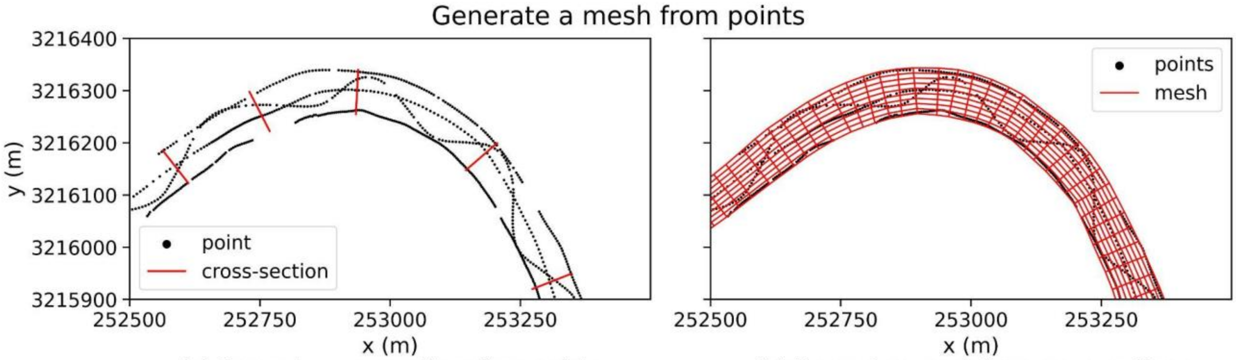
(b) Flow-oriented coordinates (S-N)

Figure 6. An example of transforming coordinate systems from Brazos River

5.3. Bathymetry Cross-sections and Mesh Generation

Most bathymetry data collected from single- or multi-beam surveys, like the data in Figure 7, are not directly useful for a scientific analysis. For example, a 1D analysis or modeling requires bathymetry data in the form of cross-sections, and a 2D analysis requires a mesh. RIMORPHIS includes functions to generate cross-sections and surface meshes from survey points for 1D and 2D analysis, respectively. The input data can be in a variety of forms including irregularly spaced points, points collected along cross-sections or uniformly spaced multi-beam points. RIMORPHIS uses a unique approach to plot the bathymetry points in (s,n) space and find optimal locations for cross-sections based on the density of survey points. Alternatively, the user can specify the locations of cross-sections. After the cross-sections are created, they are linearly interpolated to create a bathymetry mesh as per user input based on the methodology proposed by Merwade et al.

(2008). Getting cross-sections from a mesh, an inverse process to generating a mesh, is also included in RIMORPHIS based on user input of cross section spacing.



(a) Generate cross-sections from points (b) Generate a mesh from cross-sections

Figure 7. An example of generating a bathymetry mesh from points or cross-sections. To generate a mesh from a point, the cross-sections are set up first (a) and the interpolation is applied to construct a mesh (b) A mesh can also be generated from cross-sections.

The procedure described here is implemented in producing the mesh visualization shown in Figure 4, where field collected data are used to generate cross-sections and the mesh. However, as discussed in the Introduction Section, bathymetry surveys are not available continuously for most reaches. In some instances, there are no data available for any reach within the stream network. To address this gap, RIMORPHIS will include tools to generated bathymetry in data scarce regions. The first tool uses a deep learning (DL) based framework for estimating river geometry from readily available datasets such as river centerline, drainage area, sinuosity, and channel width.

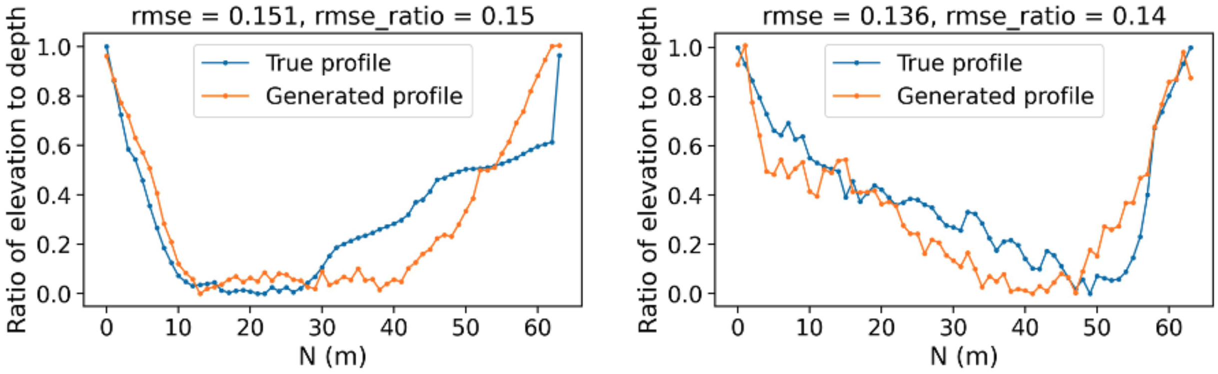
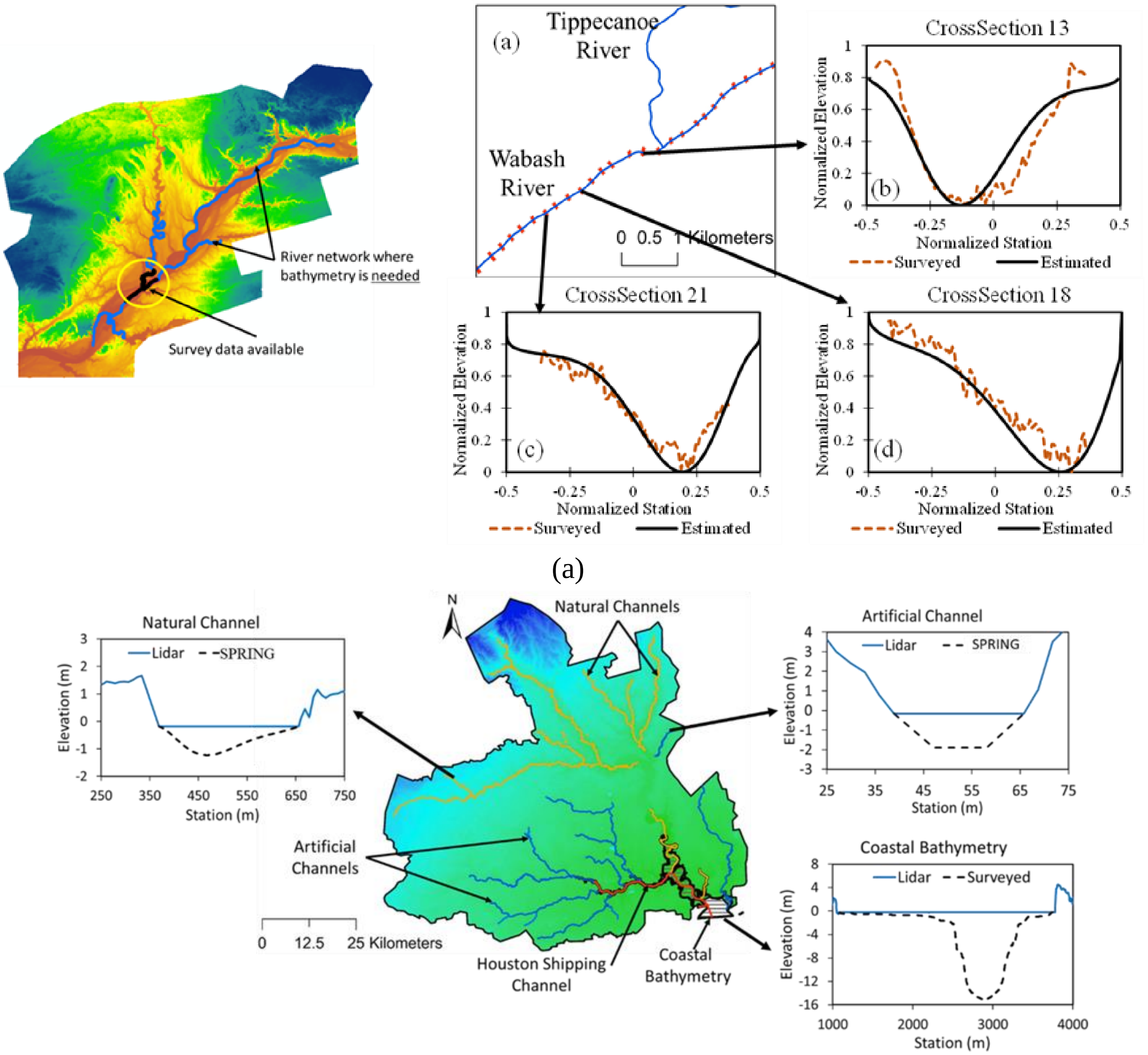


Figure 8. DL model-based estimation of river geometry from publicly available datasets in data-sparse regions

The DL model is pre-trained on reaches where survey bathymetry data are available and can be deployed on reaches with similar river characteristics. Such a framework can also be regularly updated as more bathymetry data become available to reduce the model uncertainty. Preliminary results (Figure 8) for the Brazos River in Texas and Mississippi River in Minnesota have yielded encouraging results. Efforts are ongoing to create a generalized model that can be widely implemented across the United States.



(a)

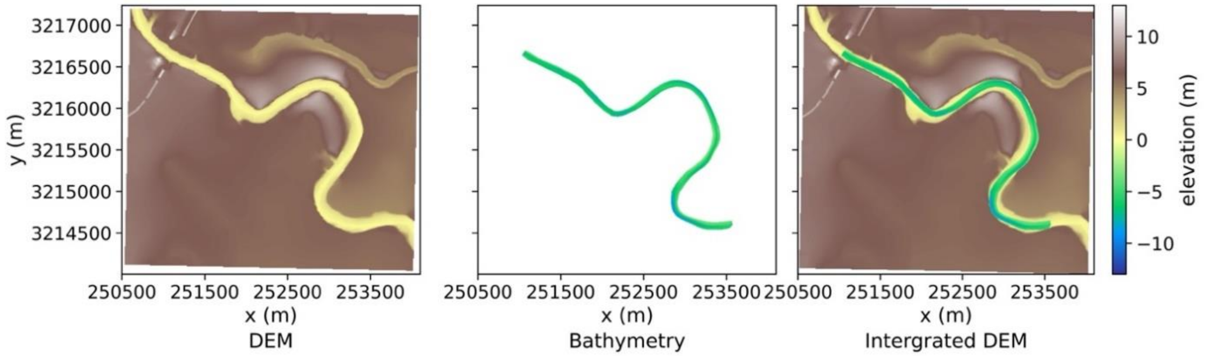
(b)

Figure 9. Figure demonstrating SPRING's ability to (a) estimate bathymetry along a river network from limited surveyed data (Wabash River, IN) and (b) incorporate variability in channel geometries across different reaches in a river network (Houston, TX). [Figures adapted from Dey et al., (2022) and Saksena et al., (2021)]

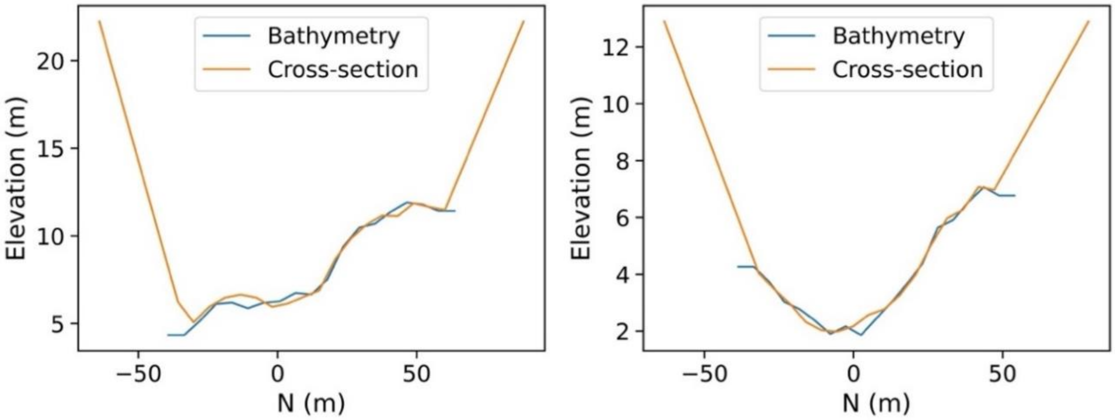
Another tool uses the System for Producing River Network Geometry (SPRING, Dey et. al., 2022) to create 3D representations of river channels by: (i) updating river centerlines, (ii) delineating banks and areas of missing bathymetry, and (iii) incorporating conceptual bathymetry to improve channel geometry representation. SPRING can take a DEM and an approximate estimate of centerline, such as NHD flowlines, as input to check for spatial correspondence and update the centerlines such that they are representative of the river network in the DEM. Banks are delineated using the lateral slope-break method. SPRING improves the river geometry characterization in the DEM by burning conceptual shapes denoting river channels. These can range from simplistic triangular or trapezoidal to more complex shapes that can incorporate anisotropy in river geometry (Figure 9).

5.4. Integrating Bathymetry with DEM

Most bathymetry surveys are limited to riverbanks, but many applications such as flood modeling require information beyond riverbanks to floodplains. On the other hand, most digital elevation models (DEM) contain floodplain topography, but do not include river bathymetry. Considering the availability of river bathymetry data and capability to process these data to create a mesh, RIMORPHIS can integrate this mesh with a DEM to provide an continuous DEM that includes both river bathymetry and surrounding topography. For a given area of interest, RIMORPHIS can access a DEM from the USGS National Map v.2 (TNM v.2), clip it to reduce the data size and then perform the integration of river bathymetry and DEM using raster operations (Figure 10a). Further, these tools can be used to complete partial bathymetric cross sections by using bank height data from DEMs as shown in Figure 10b.



(a) Example of integrating a DEM with bathymetry



(b) Creating complete cross-sections by including bank heights from DEM

Figure 10. Creating complete cross-sections by including bank heights from DEM

5.5. Interoperability with HydroShare

HydroShare (Tarboton et al., 2014) is a community resource or repository for publishing data and tools for broader community access. RIMORPHIS is interoperable with HydroShare and enables the following functions: (i) search HydroShare for data published by RIMORPHIS users and import them to RIMORPHIS for visualization, download, or as inputs to its suite of tools: (ii) run tools on RIMORPHIS and publish or share the results on HydroShare; and (iii) access HydroShare from RIMORPHIS and search for river bathymetry data to bring them into RIMORPHIS for processing. Interoperability between RIMORPHIS and HydroShare not only reduces redundancy in terms of processing the same datasets or reaches but also promotes data sharing and curation in line with FAIR (Findable, Usable, Interoperable and Reproducible) principles.

6. Discussion and Conclusion

River morphology is the backbone for the hydrological and hydraulic modeling of river systems. In the late 1900s, river bathymetry data were mostly collected through traditional surveying in the form of cross-sectional surveys. An important paradigm shift was initiated in the 1980s when acoustic technology was adapted for measurements in river environments. With the advances in echo-sounders and GPS in the early 2000s, river bathymetry surveys began using boat-mounted single- and multi-beam echosounders. Besides these ground measurements, airborne green lidar has also been used in mapping river bathymetry in shallow streams. Despite all these advances, there a several issues related to river morphology data as identified in the Introduction section. Broadly, these issues are related to: (1) data discovery and access; (ii) availability over large domains; (iii) pre-processing tools; and (iv) data integration tools.

For data discovery and access, the current version of RIMORPHIS (https://rimorphis.org; Figure 4) lets users to access the USACE eHydro repository and download the data in the form that users can use in the form of cross-sections or a 3D mesh. The data can be downloaded in multiple forms thus allowing users the flexibility to get data in the format and type of their choice. While eHydro is just one resource, the RIMORPHIS framework is capable of extending this functionality to other resources. Interacting with any resource, however, requires some standardization on the data provider end. Our current community building and engagement efforts with data providers and users is creating the necessary dialogue and action to enable this interaction with additional resources. We are currently working with the USGS to discover and access river bathymetry data from ScienceBase (sciencebase.gov) so users can use and download the data for their applications.

While connecting with repositories from government agencies is one way of making river morphology data accessible, rivers are surveyed by many researchers for their scientific applications. RIMORPHIS can act as a gateway to these data in different ways. For example, any user can implement RIMORPHIS tools by uploading their data to the platform As a part of this process, the users will have the option to make their data available either through RIMRORPHIS or by pushing the data to HydroShare, a public repository for sharing and publishing hydrology data. Alternatively, if any researcher has uploaded their river morphology data to HydroShare, a user can search and access these data through RIMORPHIS. Currently, RIMOPRHIS does not store any data locally on its platform, but depending on future community needs and funding, this capability can be implemented. Overall, the open access to structured geomorphology data and the interoperability offered by RIMORPHIS with different data resources make possible the reuse of the digital assets for comparative studies of simulation model performance or for investigating long-term changes in the morphology of river systems across time and space.

With access to data from multiple repositories, RIMORPHIS can identify data gaps along a reach or stream network. Existing tools in RIMORPHIS can filter a large dataset to extract cross-sections to create a representative surface for the survey region. The ongoing development and implementation of the deep learning tools and SPRING tools will enable filling these gaps to create a continuous representation of river bathymetry over single reach or an entire stream network. Thus, observed data can be combined with generated data to create river morphology over large domains, which is needed for many large scale hydrology and flood models, including the National Oceanic and Atmospheric Administration's (NOAA) National Water Model.

Several tools within RIMORPHIS, both currently operational and that are under development, provide both pre- and post-processing capabilities that can be implemented on the data accessed through RIMORPHIS or on the data uploaded by the users or remotely through the RIMORPHIS API. Overall, the current version of RIMORPHIS has been iteratively designed to validate its competency in tackling complex challenges relating to data access, processing, and intersystem communication on a limited scale and datasets. However, the system's handling capabilities with reference to computational workload have not yet been benchmarked beyond a restricted, controlled user group. Next steps involve optimizing and solidifying the RIMORPHIS cyberinfrastructure to bolster its scalability, in order to pave the way for seamless and resilient implementation at a national level across the Contiguous United States (CONUS). This paper presents a high-level vision and overview of RIMORPHIS and its function. A detailed discussion of the development, implementation, and testing of some of the tools is outside the scope of this paper and will be covered in separate journal articles.

7. Software and Data Availability

The RIMORPHIS web platform is freely available at https://rimorphis.org/. Datasets used in the platform are available freely through respective federal agencies and organizations. These include the USACE Hydrographic Surveys (eHydro) available at https://navigation.usace.army.mil/Survey/Hydro and the USGS DEM available at https://apps.nationalmap.gov/downloader/#/

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