Spatial Intelligence (SI) and Participatory Geographic Information Systems (pGIS): A Socio-technical Bridge to Increase the Inclusion and Participation of Indigenous Communities in Critica Infrastructure and National Security Planning

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Main Research Question: To what extent can SI and pGIS serve as collaborative mechanisms to illuminate policy "blind spots" and operationalize Indigenous-preferred engagement models within U.S. lifeline sector planning?

Hypothesis 1: If Indigenous communities leverage SI and pGIS tools from the outset, then previously "invisible" cultural and governance nuances become visible, allowing for more precise policy provisions.

Hypothesis 2: If community-led participation is treated as an iterative process, then initial use cases will generate a "pathway effect," uncovering successive opportunities for deeper integration and risk reduction.

1 Background

- **Inclusion Gap as Discovery Point:** While current frameworks may inadvertently overlook Indigenous perspectives, these gaps represent critical opportunities for collaborative policy innovation.
- **Socio-Technical Leverage:** SI and pGIS serve as "entry points" for community-led science communication, revealing cultural nuances that standard models miss.
- **Iterative Participation:** Engaging community members in network analysis creates a "Use Case Loop," where identifying one blind spot naturally leads to the next policy improvement.
- **Proactive Engagement:** Research indicates a strong desire for participation; providing technical mechanisms allows communities to define how they prefer to engage.

U.S. Critical Infrastructure Sectors

Figure 1: U.S. Critical Infrastructure Sectors (lifeline sectors circled) (Huntsman Security, 2026).

Socio-Technical System (STS) Theory Web

Figure 2. Socio-Technical Systems Diagram (Davis et al., 2014; Hughes et al., 2017).

2 Methodology

Literature Review
- **Primary Sources:** U.S. Code, State Regulations, & Statutory Language
- **Secondary Sources:** Peer-reviewed journals & policy databases

Policy & Cultural Analysis
- **Frameworks:** National Security & Critical Infrastructure Policy (ex. NSM-22)
- **Context:** Traditional norms, training, & upskilling modes

Conceptual Ecosystem Mapping
- **Interaction:** Indigenous Community-to-Lifeline Sector mapping
- **Pathways:** Identifying "Blind Spots" in communication flows

Comparative Analysis
- **Governance Models:** Extractive vs. Participatory structures
- **Opportunity:** Analyzing gaps in existing policy provisions

Evaluation of SI and GIS Capabilities
- **System Logic:** SI/(p)GIS as socio-technical enablers
- **Inclusion:** Designing for civic vs. technical-only use

3 Current Enablers of Collaborative Planning

Principles:

- **C.A.R.E.**: **C**ollective Benefit, **A**uthority to Control, **R**esponsibility, **E**thics
  - *Developed by Indigenous data sovereignty networks to protect Indigenous rights and interests in data*
- **F.A.I.R.**: **F**indable, **A**ccessible, **I**nteroperable, **R**eusable
  - *Data discovery and reuse, especially by machines and automated tools*

Core Technologies & Approaches of Focus:

- **Cybercartography**, **digital twins** (synthetic data), **drone-based data collection**
- **GIS-enabled mobile/web tools** and co-developed platforms
- **3D and scenario-based modeling** for simulation over disruption

4 Applied Use Cases from the Literature

Water: **Synthetic Sewer Pipe Networks**

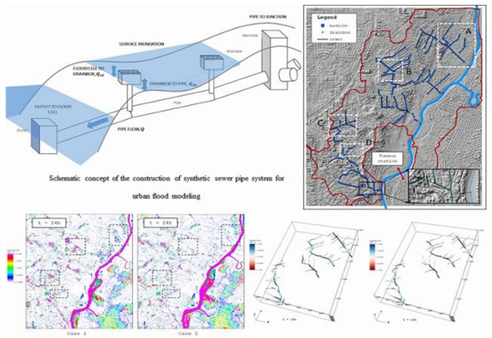

Figure 3. Synthetic sewer pipe system schematic and typology in urban sewer infrastructure (Dasallas et al., 2023).

Synthetic network modeling can support planning and emergency response by mapping water and wastewater systems with community-informed routes and local knowledge.

Synthetic routing, integrating GIS and traditional maps, can model community pathways and identify access gaps while maintaining Indigenous data stewardship.

Transportation: **Synthetic Navigation Routes from Traditional Maps**

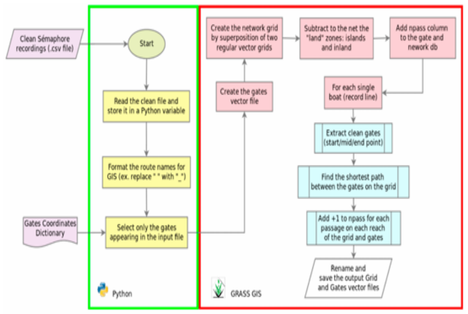

Figure 4: Creation of a synthetic route from boat navigation. (Minelli et al., 2021).

5 Factors to Consider

VISUALIZING SOVEREIGNTY: AN EGOCENTRIC SOCIAL NETWORK ANALYSIS OF A US-BASED INDIGENOUS COMMUNITY

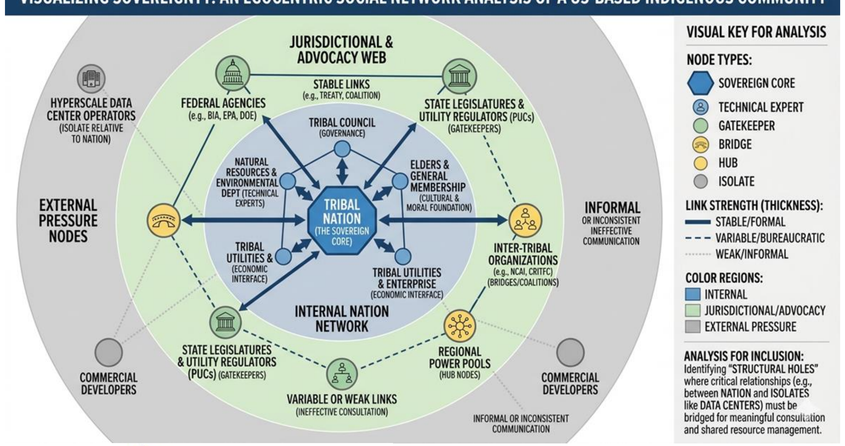

Figure 7. Image created using Google Gemini (Gemini 3 Flash) on April 5, 2026, from the prompt: "An egocentric social network analysis diagram of a US-based Indigenous community showing a 'Sovereign Core' at the center, with jurisdictional and external pressure layers.

Choropleth Map of Native American Tribes by State - 2026

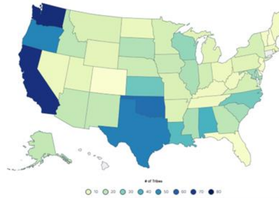

Figure 6. Native American Tribes by State (World Population Review, 2026).

- **A:** Effective modeling requires mapping actors, influence, and decision pathways
- **B:** Social Network Analysis (SNA), for example, can identify nodes, relationships, and power dynamics, supporting more accurate, context-aware system design

The demonstration image in Figure 7 illustrates LLM interpretation of SNA requests; not based on direct stakeholder collaboration.

6 Working Model for Collaborative Ue of Socio-Technologies in National Planning

Figure 8. The 9 A's Framework for Agency-Centered Socio-technical Systems Development (Suarez, 2026).

Model in development

System Reality
- Socio-technical systems encode behavior and power structures, and ignoring actors and influence pathways creates critical blind spots

The Risk
- Technical optimization can override local governance dynamics causing systems to amplify embedded bias; Inclusion becomes symbolic if agency is not preserved

Safeguards
- Respect tribal sovereignty and jurisdiction
- Strengthen data governance and contractual protections
- Protect community-controlled information
- Use pGIS as a participatory design approach

Proposed Response: **The 9 A's Framework**
- Agency-centered evaluation model applied across individual, community, and institutional levels
- Enables continuous feedback and integration
- Embeds human-in-the-loop governance across the full lifecycle

7 Results

Strategic Integration: SI & pGIS
- ***Data Resiliency:*** Enables modeling in data-constrained zones via community-validated, hybrid datasets.
- ***Human-Centered Governance:*** Technology augments governance; analytical tasks may be delegated, but decision authority remains sovereign.
- ***Ethical Framework:*** Requires sustained engagement guided by stewardship, justice, and relational trust.

System Gaps & Implications
- ***The Gaps:*** Current AI/ML models often omit cultural nuance, embedding structural bias and ignoring community knowledge.
- ***Policy Impact:*** Intentional inclusion reveals statutory gaps, necessitating expanded representation to reflect real-world resource impacts.

8 Recommendations

- **Sovereign Policy Agility:** Leveraging state-level governance to modernize legal language and institutionalize intuitive, iterative communication loops.
- **Accountable Acquisition:** Ending the "Black Box" effect through transparent data governance and contracts that protect Indigenous Knowledge (IK).
- **Socio-Technical Parity:** Designing systems that serve as core community services, grounded in "Day-in-the-Life" SNA rather than technical assumptions.
- **Relational Security:** Rebuilding trust through "Listen-First" academic outreach, ensuring information is accessible to the community on a use-case basis.

9 References

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