Visualizing water infrastructure with Sankey maps: a case study of mapping the Los Angeles Aqueduct, California

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visualizing water infrastructure with Sankey maps: a case study of mapping the Los Angeles Aqueduct, California

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ABSTRACT
Creating resilience for urban water supply systems requires innovative thematic visualizations of the interface between infrastructure, ecology, and culture to viscerally engage lay audiences in the policy making process. Sankey maps (a hybrid Sankey diagram/flow map) embed the systemic accounting of flows between sources and sinks into a spatial framework. This allows a hierarchy of visual variables to encode environmental conditions and historical data, providing a rich multivariate context supporting public discourse, policy making, and system operations. The article features a Sankey map of the Los Angeles Aqueduct system (California, USA) (not to scale).

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Flow visualization; public engagement; sustainability; visual variables; water infrastructure

1. Introduction
Creating compelling visualizations of the interface between infrastructure, ecology, and culture that are accessible to the public and experts (policy makers, regulators, and system operators) is crucial for society to become more resilient and sustainable. Creating static depictions of the dynamic conditions of ecotechnical infrastructural systems (such as urban water supply systems) are cartographic conundrums; a cartographer must balance between spatial accuracy and simplified visualizations that are legible to a wider audience. Sankey maps, which are hybrids of Sankey diagrams and flow maps, provide a thematic framework for spatially (and temporally) visualizing real-time conditions together with related multivariate environmental and historical data, data that is essential to providing a context for lay audiences and experts to understand the system.

This article explores design concepts and esthetics used to produce the Sankey map of the Los Angeles Aqueduct (LAA) system (Main Map & Figure 5), created for an exhibit marking the 2013 centennial of the LAA by the Aqueduct Futures (AF) Project at California State Polytechnic University, Pomona (2012–2015). AF featured a series of courses and events engaging an interdisciplinary team of faculty and one hundred and 53 baccalaureate and master level students, mapping and indexing the nexus of water, energy, ecology, and culture created by the LAA (Lehrman, Delgado, & Alm, 2013). Student work was incorporated into the design of the AF exhibit (6 November–6 December 2013) and the After the Aqueduct group exhibition (4 March–12 April 2015) at Los Angeles Contemporary Exhibitions, Hollywood, California (Figure 1).

1.1. Mapping the water systems of Los Angeles
Over the course of the twentieth century, Los Angeles, California created one of the most complex and extensive inter-basin water supply systems in the world (Figure 2), enabling the entire metropolitan region to prosper, despite the drought-prone semi-arid Mediterranean climate. Lehrman (2016a, 2016b) covers the environmental history of Los Angeles’ water supply system and the LAA’s impacts on the Owens Valley.

Today, three massive aqueducts supply Los Angeles with most of the water needed for the metropolis to thrive (Figure 2):

- Los Angeles (Owens River) Aqueduct, completed in 1913 and expanded in 1941 and 1970, once provided over 50% of the city’s water but now delivers just 29%, by gravity from the Eastern Sierra watersheds of Mono Lake and the Owens River. It is owned and operated by the Los Angeles Department of Water and Power.
- Metropolitan Water District’s Colorado River Aqueduct, completed in 1939, provides 9% of the city’s water from the over-allocated and heavily litigated Colorado River Basin, an area that encompasses 5 states.
- California Aqueduct (also known as the State Water Project, as it is operated by the State of California),
built 1963–1972, supplies 48% of the City’s water from Northern California watersheds via massive pumps elevating the water from sea level to 600+ meters, to cross the Tehachapi Mountains.

Mapping these aqueducts and their associated aqueductsheds using conventional cartographic methods (as in the simple lines on a map seen in Figures 3 and 4) fails to viscerally convey the quantities of water being transferred or provide contextual data to evaluate the Aqueduct’s status and environmental impacts.

Of the various historic maps delineating the route of the LAA, a few are significant for their beauty and craft: the City of Los Angeles Board of Water and Power Commissioners’ (1908) topographic map, Mulholland’s plan and section (1916, Plates No. 4 & 5) which charted construction progress, and The Figure 1. Installation of the Los Angeles Aqueduct Sankey map (center) as part of the After the Aqueduct exhibit at Los Angeles Contemporary Exhibitions, Hollywood, California. Photo by author.

Figure 2. Aqueductsheds (watersheds and aqueducts) supplying metropolitan Los Angeles, with average annual precipitation in the watersheds, annual average river flow, dates of completion for the aqueducts and water agency. Indicating spatial extents of Figures 3 and 4. Albers projection, NAD27. By the author. Sources: (Engelbert & Scheuring, 1984; Franken, Verdin, Worstell, & Greenlee, 2003; Heberger, 2013; Lehrman, 2008; Los Angeles Bureau of Engineering, 2015; United States Natural Resources Conservation Service, 1997; Phizzy, 2009; Poppenga & Worstell, 2008; United States Geological Service, 2004, 2005). Note: Complexity of this figure was optimized for onscreen viewing and print, refer to the full-size supplemental map for all the nuanced graphic tactics discussed in the article.
California Water Atlas’s (Kahrl, 1979, pp. 34–35) comparison of the LAA with the Colorado River Aqueduct. Except for Kahrl’s, these maps lack flow and temporal data (such as peak and average flows, or capacity). Likewise, AF’s initial catalyst for designing a compelling and visceral quantitative spatial visualization of the Aqueduct was the indecipherable diagrams provided by the Los Angeles Department of Water and Power (LADWP) on the real-time Aqueduct data web page (Los Angeles Department of Water and Power, 2013). LADWP’s ‘dashboard’ is all-but-indecipherable through poor design and a lack of units (to say nothing of providing historical context or attempting to make visible the quantities).

1.1.1. Mapping time
In Desimini & Waldheim’s (2016) curated catalog of the cartographic techniques in representations of landscape features, there is a scarcity of maps that feature temporality, despite the fascination of landscape
urbanist theorists (such as Waldheim) with emergent ecological conditions. Time is implicit in their discussion of the stratigraphic columns of geologic maps, but this is the limit of their coverage.

Aigner, Miksch, Schumann, and Tominski (2011) introduce their comprehensive survey of ‘time-oriented’ visualization methods with a history of time-based graphs, from Jacques Barbeu-Dubourg’s carte chronographique (1753) and Playfair’s Atlas (1786) to Charles Joseph Minard’s 1861 chart of Napoleon’s 1812–1813 failed campaign into Russia (see the next section). Of the 101 contemporary typologies included in Aigner et al., only 11 provide any degree of spatial organization (Flow Map, GeoTime, Helix Icons, Icons on Maps, Pencil Icons, Small Multiples, Space–Time Path, Time-Oriented Polygons on Maps, Time-Varying Hierarchies on Maps, Value Flow Map, and Vis-Stamp); the rest utilize abstract empirical

Figure 4. Tributaries and sources of the Los Angeles Aqueduct, in the Eastern Sierras: aquifers, wells and well fields, and areas irrigated by the Paiute. By the author. Sources: (California Department of Water Resources, 2013; Danskin, 1998; FRAP, 2002; Los Angeles Department of Water and Power, & Ecosystem Sciences, 2010, fig. 5.2; Morrow, 2014; Mulholland, 1916; Sauder, 1994, fig. 8.2; National Park Service, 2015; Raumann et al., 2002). Note: Complexity of this figure was optimized for onscreen viewing and print, refer to the full-size supplemental map for all the nuanced graphic tactics discussed in the article.
or ordinal frames. All 11 (and most of the 101) appear to serve a narrow, expert audience; they fail to provide the qualities of legibility a lay audience needs, such as good graphic design.

1.1.2. Flow maps

Minard’s chart is the most frequently (but undeservingly) cited example of a flow map, thanks to the prolific graphic evangelizing of Tufte (2001). Flow maps were pioneered by Henry Drury Harness (1804–1883), with his 1837 map of travel around Ireland (Jenny et al., 2017). Flow maps have matured into a common means to visualize population migration, transfers of goods, or economic indicators at a continental or global scale. As high-level abstractions, they condense nuanced spatial origins and destinations to a few centroids of geographic/political regions, or cities. While flow maps may implicitly reveal movement along highways, railroads, or air networks, visualizing net transfers is the focus, not the functionality of the networks and infrastructure.

Much of the contemporary research into flow maps falls into either legibility/visual preferences studies (Jenny et al., 2016, 2017; Johnson & Nelson, 1998; Koylu & Guo, 2017), or the development of automated mapping algorithms (Boyandin, Bertini, Bak, & Lalanne, 2011; Buchin, Speckmann, & Verbeek, 2011; Guo, 2009; Phan, Xiao, Yeh, & Hanrahan, 2005; Stephen & Jenny, 2017), which are both outside the scope or aims of this paper. Koylu and Guo (2016) attempt to resolve the conflicting findings of prior research in visual preferences and the efficacy of origin/destination flow map design tactics. Soundararajan, Ho, and Su (2014) analyze the efficacy of design features in flow maps, but their discussion about visual comprehension and communicating with the public is weak and underdeveloped.

1.1.3. Sankey diagrams

What would otherwise be known as ‘flow diagrams’ bear the eponymous designation of Matthew Henry Phineas Riall Sankey (1853–1926), the steam power engineer who first published a diagram accounting for the energy flows in a steam engine (Sankey, 1898; Schmidt, 2008a). Schmidt (2008b) follows up his history of Sankey (flow) diagrams with a review of the contemporary variants and applications but fails to delve into their esthetics or attributes that contribute to visual comprehension. While Meadows (2008), in her Thinking in Systems, does not touch on the etymology of her vocabulary of ‘sources’, ‘sinks’, ‘reservoirs’, and ‘limits’, are implicitly linked to Sankey’s work.

Today, Sankey diagrams are frequently deployed to visualize regional or national energy use, or to accompany life-cycle accounting of industrial commodities. Direct precedents to our LAA map include US Army Corp of Engineers’ (1958) Project Design Flood Hypo-Flood 58A and Meade’s (1995) diagrams of the Mississippi River system. Colorado Water Conservation Board’s 2017 map juxtaposes scaled arrows of stream flow for wet and dry years – though it does not provide a legend for the arrow widths as numeric quantities are annotated. Lawrence Livermore National Laboratory has produced a series of Sankey diagrams visualizing all water use for the nation and each state (Smith, Belles, & Simon, 2011), but their abstract accounting is entirely removed from the geographic and ecological context. Curmi et al. (2013) covers the adoption of Sankey diagrams for visualizing the energy-water nexus for northern and central California and makes the case that Sankey diagrams are effective means to communicate with resource managers and policy makers.

Hybrid diagrams and maps are another means to balance conflicting heuristics through the design process, such as the richness discussed by Fathulla (2008). Lupton and Allwood (2017) define a ‘hybrid’ Sankey diagram for multi-dimensional data by hierarchically aggregating flows to improve comprehension, but their resulting examples are visually awkward.

1.2. Esthetics and legibility of water supply system diagrams

Maps are a form of visualization (MacEachren, 2004) in which esthetics are critical to supporting the comprehension and persuasiveness of exploratory and expository data visualization (Lang, 2010). In our case of mapping inter-basin water transfers, there are quantitative, qualitative, spatial, and temporal aspects to visualize, requiring the visualization to provide both exploratory and expository functions. Bennett, Ryall, Spalteholz, and Gooch (2007) emphasizes readability and comprehension as the key esthetic heuristics for graphs (including Sankey diagrams), with syntactical and semantic issues contributing to visceral, behavioral, and reflective processing. Buchin et al. (2011) discuss the qualities that make a flow map ‘good’, but their criteria are simplistic: reduced visual clutter, minimizing the crossing of flows, and using curved lines. Flow map design principles proposed by Jenny et al. (2016) are also reductive: use curved flow lines; use arrows instead of tapers; and provide nodes to identify sources and sinks.

Buchin et al. and Jenny et al. ignore the principles of ‘good’ graphic/artistic composition that Tufte (2001) broadly applies to information design. These compositional rules include: dynamic visual balance (to keep the viewer engaged); clear hierarchies (so the viewer knows what is significant); use of proportions and a clear visual language (so everything works together); and interplay between the figure and ground (to keep it interesting), otherwise called ‘soundness’, ‘attractiveness’, and ‘utility’ (Vande Moere & Purchase,
These graphic/artistic esthetic composition criteria are not the same as ‘graph drawing esthetics’ where minimizing edge crossings, limited bends to edges, creating local symmetries, and maximizing the angle between edges at nodes are significant factors for creating legibility (Purchase, Pilcher, & Plimmer, 2012). Both have relevance when designing for legibility and accessibility by the public.

Human–computer interface research into persuasive displays has identified how viscerally clear, legible and playful graphic grammar (Chen et al., 2009; Pearce, 2008; Valkanova, Jordà, & Vande Moere, 2015) enable the public to connect to and comprehend complex data visualizations. Designing visceral and playful glyphs and graphics requires engaging the indexical (Atkin, 2013; Moere & Patel, 2009; Offenhuber & Orkan, 2015) to bridge between the phenomena being mapped and the glyphs being used to represent the conditions.

1.2.1. Visual variables

Visual variables (dash styles, size, value, texture, color, orientation, and shape) provide the means to encode multivariate data into flow diagrams/maps (Bertin, 1983; Wilkinson, 1999). Holten, Isenberg, Wijk, and Fekete (2011) explores how visual variables, including curvature/sinuosity, hue, tone, value, line taper, line dashes, arrowheads, and glyphs (or decals) impact the legibility of connections between nodes in depictions of networks as graphs. Agrawala, Li, and Berthouzoz’s (2011) methodology for visualization design principles (identify, instantiate, and evaluate) supports using variables that relate to the subject of the map as a means to create a visceral and compelling visualization. Blok (2005) explores how dynamic visual variables can depict changing conditions in animated maps, where several of the practices identified are also effective means to indicate changed conditions on static two-dimensional maps.

Most of the studies cited so far are flawed by their reductive scholarship studying isolated (and simplified) aspects of graphs and maps; they overlook the power of visual richness and good graphic design to engage the public. This is also the point at which to distinguish between research into automated data visualization techniques/human–computer interface (not to diminish this work in general), and the qualitative and intuitive realm of esthetics and graphic design. Intuitive graphic choices by an experienced designer are not ‘arbitrary or capricious’ [per Robinson as quoted in MacEachren (2004)] when grounded in both scientific methodology and esthetics. An experienced designer can help create graphic legibility that cannot be replicated by algorithms or distilled from visual legibility studies.

2. Designing the LAA Sankey map

Our initial plan for the AF exhibit and website was to create a series of flow diagrams for the water supply of Los Angeles covering each decade between 1851 and 2010 (the range of our data set). Due to limited time and space constraints, our ambition was curtailed to creating the single flow diagram depicting the average conditions for 2001–2010. While the Sankey map for the Los Angeles City Hall exhibit was printed on a 40 × 60-inch (102 × 152-centimeter) panel, we strove to design a diagram that would remain legible when scaled down to fit on a computer screen as a rasterized image.

The Sankey map shared the exhibit’s CMYK color palette, typographic styles, and AF logo/word mark designed by M. Noriega (a 4th year baccalaureate graphic design student in Prof. Lee’s AF project-sponsored ART499) and the author. Initial development of the Sankey map was the endeavor of two BSLA students, S. Bhalinge and A. Placido, in the author’s spring 2013 Exhibit Design Practicum. The final version of the map included in the Los Angeles City Hall exhibition was created by the author in the fall of 2013. The version accompanying this article includes revised line widths and geometry created by the author for the 2015 After the Aqueduct exhibit (Figure 1) and the project’s website.

To enhance the overall visual clarity and to match the granularity of the available data, we used a simplified depiction of the hydrology (see Figure 5) by aggregating all the tributary streams feeding Mono Lake and Owens River (see Figure 4) into a few nodes representing each watershed, and clustering the nine Owens Valley wellfields into northern and southern nodes. These design decisions align with research into flow map visual preferences that aggregation of flow paths (Koylu & Guo, 2017; Phan et al., 2005; Stephen & Jenny, 2017) and clustering of edges in graphs (Cui, Zhou, Qu, Wong, & Li, 2008; Purchase et al., 2012) enhances comprehension.

While our final Sankey map is not strictly drawn at a specific spatial scale, it was designed using a 1:375,000 base map of the Aqueduct and surrounding terrain. We chose to retain the distinctive outlines of Mono Lake (with bathymetry), Owens Lake (with dust mitigation), and the border of Los Angeles as recognizable landmarks, while all other features were stylized. For legibility, specific geometric features were manually enlarged or reduced to convey their significance (such as the distinctive trace of the LAA around the perimeter of Antelope Valley), while also adhering to the self-imposed convention of locating all water sources on the left, water sinks (end users, evaporations, and leaks, e.g.) on the right, and for water to flow from top (north) to bottom (south) of the panel. Fidelity to these rules required locating the Colorado River Aqueduct (which enters the city from the east), and the California Aqueduct (entering from the north) on the left side of Los Angeles, so tails were added to the arrow that indicated the direction.
Figure 5. Simplified Sankey map of the Los Angeles Aqueduct (LAA) visualizing average annual flows from 2003 to 2013. Color gradients distinguish between sources and sinks, pumped groundwater and surface flow. Conduit capacity and historic averages are embedded in the visualization to provide temporal context. See the featured map for the glyphs that convey velocity, streams versus pipes, and evaporation. Not to scale. See Figure 2 for the regional context of the LAA, while Figures 3 and 4 provide geographic details of aqueduct system. By the author and the Aqueduct Futures project. Sources: (Botkin, 1988; Bureau of Los Angeles Aqueduct, 1907, 1908, 1909, 1910, 1911; United States Bureau of Reclamation, 2012; Lee, 1912; Lee, 1906; California Department of Public Works, 1923, 1930, 1937; Christopher, 1930; Danskin, 1998; Department of Sanitation, 2006; Hoffman & Stern, 2007; Hyde, 1915; Inyo County & City of Los Angeles, 1990; Kahrl, 1976, 1979; Kelly, 1913; Los Angeles Department of Sanitation, 2015; Los Angeles Department of Water and Power & Ecosystem Sciences, 2010; Los Angeles Department of Water and Power, 1976, 1978, 1979, 1980, 1986, 2010, 2015, 2017; Los Angeles Water Commissioners, 1902–1910; Los Angeles Department of Water and Power, 2015; Lyon & Sutula, 2011; Metropolitan Water District of Southern California, 2016; Mulholland, 1906, 1916; Orme & Orme, 2008; Orstrom, 1950; Quinton, Code, & Hamlin, 1911; Raumann et al., 2002; Rogers, 1987; Sanitation Districts of Los Angeles County, 2013; Steward, 1933; Trowbridge, 1911). Note: Complexity of this figure was optimized for onscreen viewing and print, refer to the full-size supplemental map for all the nuanced graphic tactics discussed in the article.
2.1. Visual variables

Regarding color, the palette developed by M. Noriega designated colors for each data type/geographic typology (stream, lake/reservoir, or aqueduct, e.g.). These colors were the basis for developing tonal color gradients indicating the progression from source (lighter tone) to sink (darker tone). Sanitary sewer flows were coded to brown, which was blended in a ramp with the blue sink color.

In reference to line widths, as the flow volumes ranged across several orders of magnitude (a few thousand to tens of millions of gallons), we developed a pseudo-logarithmic scale to ensure the thinnest lines would remain visible at a lower resolution on screens. After experimenting with various algorithms to generate our line widths, we arrived at a final formula: Square Root (Flow in mGal/162,000) × 160 points. Our nonlinear scale required significant finessing of the intersections between sources, sinks, and the main flow lines that proved to be problematic, so the author will utilize a linear scale in future iterations.

In the case of glyphs (decals), we intended to depict the LAA system for a public audience, so several stream attributes were developed into visceral design elements. Natural streams and rivers are indicated by varying the sinuosity of arrow glyphs, inspired by the eddies and meandering nature of streams. Laminar flows are observed in the aqueduct, and canals are depicted with parallel arrows glyphs. The speed of the flow (based on the slope/topography) was indicated by the length of the glyphs. Quantities were reinforced by varying the line width/arrow head size of the glyphs. For flows into sinks, liquid flows are solid lines, while evaporation is indicated by dashed glyphs. Retrospectively, these design choices for our glyphs can be affirmed by Ware, Kelley, and Pilar’s (2014) research into best design practices for displaying wind patterns and water currents.

2.2. Data aggregation and processing

Aggregating the data was the purview of the author (not the student design assistants). Annual water flow data from historic and contemporary sources were compiled into a single Excel spreadsheet via manual data entry, or as copied and pasted from Portable Document Format (PDF) files after using Acrobat Pro’s OCR tool as needed. Contemporary water and environmental data were aggregated from text files, .csv files, or PDFs into the Excel file from agency websites and reports. In the end, our flow data for the Los Angeles River and Zanja Madre system covers 1851–2010; Owens River and tributaries, 1899–2012; Mono Basin, 1941–2011; and groundwater pumping in the Owens Valley, 1941–2012. Sources for historic and contemporary data used to generate the Sankey map are listed following the article’s bibliography.

2.2.1. Unit conversion and temporal alignment

Volumetric data was converted into million Gallons (mGal) (3785 cubic meters) from contemporary sources that use a mix of Acre-Feet and cubic feet per second (CFS or ‘second feet’ by Mulholland, 1916); a few of the historic sources reported flows using archaic ‘miner’s inches’ (defined by Wikipedia as 0.025 CFS in northern California or 0.020 CFS in southern California). Imperial quantities were converted to SI units for this article (except those graphically embedded in a flow diagram). All numeric data used in the exhibition was manually rounded to three significant units.

Data used to create the flow diagram were based on the average annual quantities collected for 2001 through 2010. Temporal alignment was required as data were provided in a mix of ‘water year’ per the USGS as October 1st to September 30th (three-month offset/12 months = 25% difference), fiscal year (varying per jurisdiction), and calendar year intervals. Data intervals got normalized to calendar years by tallying the average quantities per decade (three-month offset/120 months = 0.025% difference).

Annual data for Owens Valley runoff, ground water pumping, and ground flow into the LAA/Owens River required unit conversion and normalizing different time reporting time frames. Well field pumping quantities and stream flows were aggregated geographically into three (sub)watersheds: Mono Basin, Northern Owens Valley (above Tinemaha Reservoir), and Southern Owens Valley. Delivery totals to the City of Los Angeles required unit conversion and normalization of temporal intervals.

2.2.2. Sinks calculations

Evaporation from reservoirs and lakes was calculated by multiplying surface area by evaporation rates interpolated from Goodridge (1979). For open-air reaches of the LAA, surface areas were calculated using the cross-section widths from Mulholland (1916). Evaporation rates and the surface areas of the Owens River and tributaries were not computed, as groundwater inflow rates exceed evaporation by an order of magnitude. Base flow and groundwater recharge from unlined portions of the Aqueduct were gleaned from various sources. Dust mitigation water use on Owens Lake was sourced from LADWP documents, then converted from Acre-Feet to mGal units. Customer water usage percentages are sourced from LADWP annual reports and multiplied by the total water deliveries to calculate totals per customer types. Sewage treatment quantities from Los Angeles Bureau of Sanitation and Los Angeles County required only unit conversion.

3. Conclusion: transcending the ecotechnical-societal interface

We live in a society enabled by complex water, energy, communication, and logistical systems that
are challenging even for experts to visualize. Public comprehension of our fracture-critical water supply systems is essential (Pincetl et al., 2015) in order to enable all stakeholders to engage the technocratic and insular water policy makers (at least in California) on issues of social and environmental justice, ecological water use, sustainability, recreational access, and urban/rural issues. Thus, it is a worthy challenge to design visualizations and diagrams aimed to inform and engage the public about their functions, impacts, or benefits – the essence of urban visualization. Grainger, Mao, and Buytaert (2016) identify the ‘science-society interface’ where well-designed visualizations and thematic maps are underutilized to legibly communicate complexity in the environment to the public. Equally, the engineering/society interface, the policy maker/regulator/society interface, and the utility operator/society interface are similarly deficient in their efficacy to convey nuance and complexity to the public. AF pursued crossing this technocratic interface by fostering collaborations between the author, a landscape architect/artist/graphic designer; students; and scientists/engineers to create what Gough, De Berigny Wall, and Bednarz (2014) call ‘Non-Expert User Visualisation’ to effectively engage the public.

There is a correlation between the myopic focus of policy makers and engineers who evaluate and visualize a limited set of technical criteria, and the continued construction of single-purpose infrastructure serving limited societal and ecological needs (Lokman, 2017; Lovell & Taylor, 2013), along with decision making that impedes the creation of resilience (Grainger et al., 2016).

The first step towards influencing conservation behavior is providing the public with means to understand the impacts of their lifestyle choices (Attari, DeKay, Davidson, & Bruine de Bruin, 2010). If a picture is indeed worth a thousand words, developing effective visualizations and mapping methods to convey environmental and cultural impacts needs to be a priority. Visualization for persuasion requires additional research into visual comprehension of system diagrams, developing cartographic methods to depict temporal changes in the landscape and the water-energy nexus.

Software

Design and creation of the maps and exhibition materials was in Adobe Illustrator™ (6, 7, and CC). Geospatial shapefiles were exported for editing in Illustrator with ESRI ArcGIS™ (various versions) into PDFs. Adobe Photoshop™ (6, 7, and CC) was used for image editing, compositing, and producing half-tones. Adobe Acrobat Pro™ (various versions) provided Optical Character Recognition (OCR) of scanned texts. Aggregation of numeric and text data, converting units, and the other calculations were done with Microsoft Excel™ (various versions). Writing, grammar, and spell checking was handled in Illustrator or Microsoft Word™.

Geolocation information

The maps accompanying this article encompass the following counties in California (north to south): Mono, Inyo, Kern, San Bernardino, and Los Angeles. Significant locations of the LAA:

- The northern-most point, Lee Vining Creek Intake (Mono County, CA): 37°56'10.27"N, 119° 8'4.15"W.
- Owens River intake for the LAA (near Independence, Inyo County, CA): 36°58'32.52"N, 118° 12'38.15"W.
- ‘Owensmouth’ Terminus of the Aqueduct, Sylmar (City of Los Angeles), CA: 34°19’28.99"N, 118° 29’51.76"W.

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