Defining Ordinary and Natural Conditions for State Navigability Determinations

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Cover: Rowing the Salt River below Stewart Mtn. Dam in a replica of the Edith, the boat used by the Kolb Brothers' historic 1911-12 trip down Grand Canyon (31 Aug. 2015)

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Executive Summary

Every State receives title to the beds of its navigable rivers when it joins the Union. The streambeds of navigable rivers become sovereign lands to be held for the public trust and to preserve corridors of trade and travel on the rivers. States own the beds of only the navigable waterways. Therefore, before a State can establish a claim to a specific river, it must first demonstrate that river was, or could have been, navigated by boats or used to float logs as of the time of Statehood. Furthermore, federal law requires that each river's navigability be determined at a time when it was in an "ordinary and natural" condition, rather the condition of the river at the time of the navigability determination, or at Statehood, if the river's navigability had already been altered by humans.

While federal courts require consideration of a river's navigability in its ordinary and natural condition, the courts have provided only minimal direction regarding the scientific definition of the terms "ordinary" and "natural" with respect to navigability. This paper recommends technical definitions for both terms relative to a river's flow rate, as well as to the physical condition of the river's boating channel. Ordinary flow is defined as the range of flows between base flow and the flow rate that creates the river's ordinary high-water mark. The ordinary physical condition of the river is defined as the portion of the floodplain that includes the low flow channel up to the ordinary high-water mark. Natural is defined as the conditions (for both flow rate and channel characteristics) absent the impact of humans. Recommended procedures are provided that can be used to determine if a river is still in its natural condition, or if not, how to obtain information that describes the river's boating characteristics prior to human impacts on navigability.

In addition, five case histories are briefly summarized to illustrate the types of technical issues that have been raised in recent navigability decisions in Arizona and Alaska regarding the rivers' ordinary and natural conditions.

Chapter 1:

Introduction & Background

Every State receives title to the beds of its navigable rivers when it joins the Union. The streambed lands then become sovereign lands to be held for the public trust and to preserve corridors of trade and travel on its rivers. However, most States did not act to preserve their ownership of these sovereign lands at the time of statehood, and title to some navigable waterways continued to be held by the federal government or was passed to private parties. Therefore, some states or public access advocacy groups have resorted to legal action to restore the public's title to their navigable waterways.

States own only the navigable waterways. Therefore, before a State can establish a claim to a specific river, it must first demonstrate that river was, or could have been, navigated by boats or used to float logs as of the time of Statehood. Furthermore, federal law requires that each river's navigability be determined at a time when the river was in an "ordinary and natural" condition, rather the condition of the river at the time of the navigability determination, or even at Statehood, if the river's navigability had already been altered by humans.

This paper describes issues associated with defining and describing a river's ordinary and natural condition to support a title navigability determination.

Background

The concept of title navigability dates to Roman Law, in which rivers affected by the tides where owned by Caesar to keep them open for trade and travel. This concept was later adopted into English law, under which the tidal lands were owned by the Crown, i.e., the Sovereign. The original thirteen colonies of the United States also claimed ownership of these "sovereign" lands. In the United States, the public's rights over sovereign lands were expanded to include all navigable waterways, not just those affected by the tides. As new States enter the Union, they enter on an "equal footing" to the original thirteen, and receive title to the beds of the navigable waterways.

Title navigability is a concept of constitutional law defined by court decisions, rather than by explicit legislation.[1] In one of the early court decisions, the 1870 Daniel Ball case, the US Supreme Court established the so-called "federal test," or "Daniel Ball test," for title navigability as follows:

> *"Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or are susceptible of being used, in their <u>ordinary</u> condition, as highways of commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water." (<u>Emphasis</u> added.)*

As a result of several other court decisions, such as the U.S. Supreme Court's 1922 Oklahoma v. Texas and the 1931 United States v. Utah decisions which were based on the "natural and ordinary condition" of the river, the State of Arizona codified the following legal definition that reflects how navigability is viewed by the courts:

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[1] Arizona legislation describes a process for determining navigability (ARS 37-1101 to 37-1156), but the legal foundation of the process is governed by case law established primarily by federal court decisions.

"Navigable" or "navigable watercourse" means a watercourse that was in existence on [the date of statehood] and at that time was used or was susceptible to being used, in its ordinary and natural condition, as a highway for commerce, over which trade and travel were or could have been conducted in the customary modes of trade and travel on water. ***A.R.S. § 37-1101(5)***[2]

Therefore, a post-statehood navigability determination must not be based on the modern condition of the river, nor on the condition at the time of statehood if the river had already been substantively altered, but instead on the natural condition of the river during ordinary flow conditions. Unfortunately, none of the federal court decisions or any state legislatures have provided specific definitions of the terms "ordinary" and "natural," nor did they provide guidance on how to determine the ordinary and natural condition of a river.

More recent court decisions have shed some light on the meanings of "ordinary" and "natural." In the 2012 PPL Montana v. Montana decision, the U.S. Supreme Court noted that reliance on modern day boating as evidence of navigability requires an assessment that the river's modern condition "is not materially different from" the river's physical condition at statehood (citing United States v. Oregon, 1935), particularly if "the river has changed in ways that substantially improve its navigability." This decision mandates an assessment of "material" changes from the ordinary and natural condition as it relates to historical and modern boat use. Therefore, if any evidence based on modern conditions is considered, both the modern and historical natural river conditions must be described as part of a navigability decision.

The 2010 Winkleman v. Arizona Navigable Stream Adjudication Commission (ANSAC) decision by the Arizona Court of Appeals provided more detailed information on what is meant by the "ordinary and natural" condition of a river. Specifically, the court determined the following:

(1) Navigability decisions should be based on what the river would have looked like on the date of Statehood in its "usual status, absent major flooding or drought, and without man-made dams, canals, or other diversions."
(2) The river must be considered in <u>both</u> its ordinary <u>and</u> natural condition. If the river's ordinary condition at statehood was materially disturbed by human activities, then a pre-statehood period when the river was still in a natural condition should be examined.

The Winkleman v. ANSAC decision points to several past court cases for the basis of its interpretation of the terms "ordinary" and "natural," such as:

- 1926 United States v. Holt (drought conditions are exceptional, not ordinary)
- 1922 Oklahoma v. Texas (disregard temporary high-water and consider conditions prevailing in the greater part of the year)
- 1874 The Montello (rivers must be considered in their natural state)

[2] Other states have adopted similar definitions. For example, in Alaska (AS 38.04.062(g)(1) ""navigable water" means water that, at the time the state achieved statehood, was used, or was susceptible of being used, in its ordinary condition as a highway for commerce over which trade and travel were or could have been conducted in the customary modes of trade and travel on water; the use or potential use does not need to have been without difficulty, extensive, or long and continuous."

- 1921 Economy Light & Power v. United States (man-made obstructions do not preclude navigability).

These court decisions require that a navigability determination include an assessment of the following:

- Is the river currently in its ordinary and natural condition?
- When was the river in its ordinary and natural condition?
- What were/are the ordinary and natural river characteristics with respect to navigability?

In addition, because the legal definition of navigability includes the phrase "susceptible to being used," and does not only rely solely on actual historical river use, an accurate description of a river's ordinary and natural condition is critical for a legally sound navigability determination. That is, determining what uses the river *might have* supported requires realistic information about the river's natural physical condition (depth, width, etc.) and its natural range of ordinary flows.

The goal of this report is to provide a scientific definition of the "ordinary and natural condition" for a river, and to recommend procedures for identifying and describing that condition.

Report Overview

There are two main parts of an assessment of the ordinary and natural condition of a river:

- Part 1: The physical conditions of the river channel and the river corridor
- Part 2: The flow rates occurring in the river

For each of the two parts listed above, both the ***ordinary*** condition and the ***natural*** condition must be assessed, though in practice the ordinary and natural conditions are highly interrelated. In some cases, a river's ordinary and natural condition must be determined for the period around the time of Statehood (the typical navigability determination time period), for a modern and/or post-Statehood period (to understand the context of modern and post-statehood boating records), and/or for a period pre-dating[3] Statehood (to understand the natural, pre-disturbance condition of the river). To reiterate, if the river was already disturbed at the time of statehood, then the assessment must be based on a previous time period when the river was in a natural, undisturbed condition.

This report is organized as follows to address each element of an ordinary and natural assessment for title navigability:

- Chapter 1: Introduction
- Chapter 2: Definitions of Key Terms
- Chapter 3: Natural Physical Condition of a River
- Chapter 4: Ordinary Physical Condition of a River
- Chapter 5: Determining the Ordinary & Natural Physical Condition: Recommended Methodology
- Chapter 6: Natural Flow Rate of a River
- Chapter 7: Ordinary Flow Rate of a River
- Chapter 8: Determining the Ordinary & Natural Flow Rates: Recommended Methodology
- Chapter 9: Case Histories

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[3] It is theoretically possible that a river might have been in a disturbed condition prior to and at Statehood, but has since recovered to a natural condition, at least with respect to navigability.

- Chapter 10: References Cited

The procedures described in this report are intended for use in title navigability assessments, but may also be applicable to other types of river assessments such as instream flow rights, recreational boating evaluations, or aquatic and riparian habitat studies, or for identifying ordinary high-water marks. The procedures were developed based on the author's 30 years of professional experience on navigability determinations in Arizona, Alaska, Montana and North Carolina, and numerous other river studies conducted throughout North America.[4] However, preparation of this report was not funded, authorized, or directed by any client or public agency.

[4] The author's past experience on title navigability cases includes both private and public clients, and both advocates and opponents of navigability. In Arizona, the author served as the lead investigator for the Arizona State Land Department's navigability investigations from 1992 to the present (2018), which included 39,039 watercourses, the vast majority (> 99.9%) of which the State did not argue for navigability. At the time this report was prepared, the State of Arizona was continuing to assert the navigability of portions of the Salt, Verde, and Gila Rivers.

Chapter 2:

Definitions of Key Terms

To perform an assessment of a river's ordinary and natural condition, some basic terminology must be clearly defined and understood.

Anatomy of a River. There are several components of a river that relate to navigability determinations that are frequently confused, particularly when people with limited technical backgrounds (e.g., attorneys, judges, experts from non-technical disciplines, and the general public) try to interpret scientific information or historical descriptions of rivers. In this paper, the following river components are defined as follows:

- **River**: A river is a natural, linear path of water over land, inclusive of all elements of the water conveyance system. In this report, the term "river" is meant to be synonymous with a creek, stream, or wash, and includes systems that are normally dry (ephemeral) as well as flowing (perennial), or any combination thereof (intermittent or interrupted), but does not include lakes, ponds, swamps, or other static water bodies.
- **Watercourse**: In contrast to the term "river," a watercourse is defined as the main body or portion or reach of any lake, river, creek, stream, wash, arroyo, channel or other body of water.[5]
- **River Segment**: A river segment is a portion of a river with consistent, identifiable physical navigability characteristics. Navigability determinations are made for river segments, rather than the river as a whole, to account for the natural variability of river characteristics over the full length of a river system. A river system may have both navigable and non-navigable river segments.
- **River Reach**: A contiguous portion of a river, often with one or more defining characteristics that distinguish it from other parts of the river. Alternatively, the "reach" can refer to the focus area for a study. "Reach" can be used synonymously for "segment," but does not carry the same legal connotation relating to title navigability as does "segment."
- **Channel**: A channel is commonly defined as an open conveyance of surface water having a bottom and sides in a linear configuration. However, in scientific literature, the term "channel" can be used to mean anything from the entire floodplain, to the portion of the river cross section that conveys the low flow (Figure 1). This broad use of the term "channel" has led to considerable confusion in some navigability determinations. To minimize the potential for confusion, the following channel descriptors are used in this report:
    - Main Channel. The portion of the river cross section that carries water during normal (i.e., ordinary) flow conditions. In this report, the "main" channel is synonymous with the active channel. Elsewhere, the term "main channel" has been used to mean the part of the river that carries flowing water, or alternatively, the part of a river that has the deepest flow.
    - Boating Channel. The part of the river cross section where boating occurs, typically, the parts of the main channel that are deep enough for boating; which may be only a portion of the wet part of a channel, or a portion of the main channel.

[5] See typical legal definition for "watercourse" at ARS 37-1101.11.

- Low Flow Channel. The portion of the main channel where water flows during the lowest flow conditions. In some cases, the low flow channel may be coincident with the main channel or the boating channel boundaries. The low flow channel and the boating channel often, but not necessarily, overlap.
- Active Channel. The active channel is the area between the ordinary high-water marks, or the portion of the river cross section that is shaped and most affected by ordinary flow rates. In this paper, it may also be called the "streambed" as it is the area owned by the State if the river is navigable.[6]
- Flood Channel. The flood channel includes the parts of the river cross section that are shaped by floods, even floods that exceed the ordinary high-water mark. Some classic papers in fluvial geomorphology, such as Burkham (1972) analyzed historical changes in active channel width, but neglected to use adjectives like "active" or "flood," causing confusion in Gila River navigability hearings about the fact that Burkham's channel width measurements applied to the flood channel rather than the boating, low flow, or main channel. See Case History #3 in Chapter 9 for more discussion on this point.

- **Thalweg**: The thalweg of a river is a line connecting the lowest elevation (i.e., deepest) points along the length of a river segment, a.k.a., a flow line or centerline (Figure 1). The boating channel is usually, but not necessarily, located along the thalweg alignment.
- **Ordinary High-water Mark**. This term is defined later in the Navigability Terminology section of this chapter, and is an important concept for title navigability determinations. The ordinary high-water mark is found at the margins of the active channel (Figure 1).

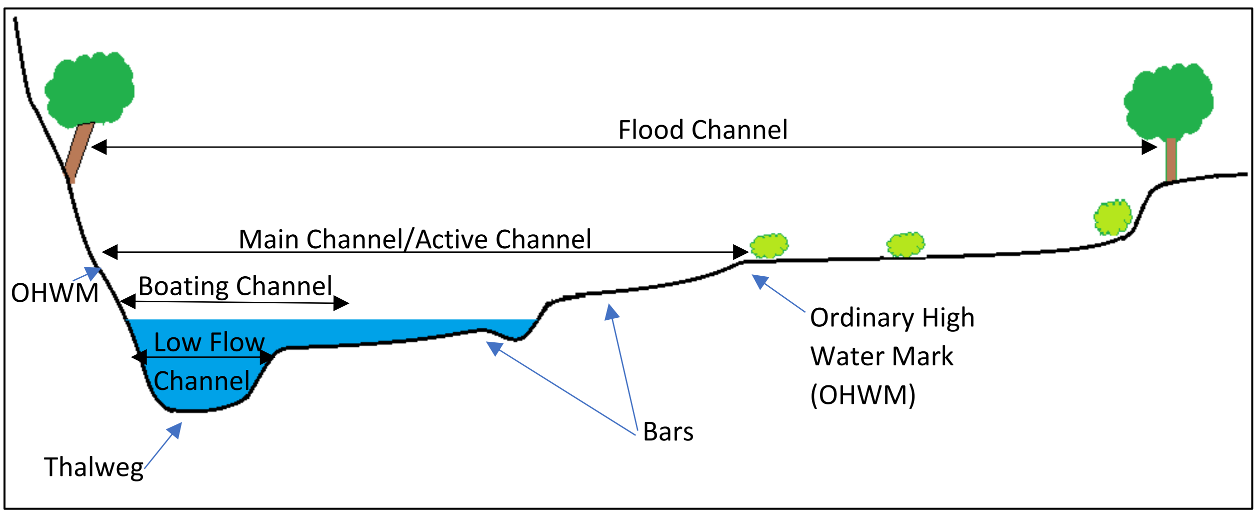

Figure 1. Elements of a riverine channel types.

- **Floodplain**: A floodplain is an area of low-lying ground adjacent to a river, formed mainly of river sediments and subject to periodic flood inundation (Figure 2). The floodplain includes the river channel. In this report, the following types of floodplains are described:
  - Active Floodplain. The active floodplain is the portion of the river that is most impacted and shaped by frequent floods, and is typically located within the ordinary high-water marks. The active floodplain may be inundated at about the 2-year frequency, although

[6] Navigability cases are sometimes called "streambed ownership" cases.

in arid regions and on flood-dominated streams, the flood frequency may be 10-years or more.
  - Regulatory Floodplain. The regulatory floodplain is the area inundated by a specific flood level defined by floodplain managers, typically the 100-year (1% chance) flood. It is often called the "100-year floodplain" and has no specific relevance to navigability determinations.
  - Geologic Floodplain. The geologic floodplain is inclusive of all terraces, floodplains, and channels along the river. In some historical or geographic documents, it may also be called the "valley bottom" or "river valley."
- **Terrace**: A terrace is a perched or abandoned floodplain adjacent to a river, which is no longer inundated by periodic flooding. Terraces are sometimes called a "bench" or a "step."
- **Bars**: A term "bar" is normally used to describe an elevated deposit of sediment (i.e., sand, gravel, or cobbles) that occurs within the main channel of a river. Bars may be exposed above, or submerged below the water surface, depending on the flow level. Bar features also may be found on the actively flooded portions of a floodplain outside the main channel.
- **Depth**. While the "depth" of a river may at first appear to be a very simple concept that does not require definition, it is in fact a rather complicated concept that is difficult to accurately quantify with a single number. Even within one segment of a river, there is always variation in the depth of a natural river. For example, at a single cross section, the flow depth varies from zero at the bank lines to a maximum depth at some point (or multiple points) between the two banks. Furthermore, the maximum and average depths vary along the length of a river segment. More detailed discussion of river depths is provided in Chapter 3.

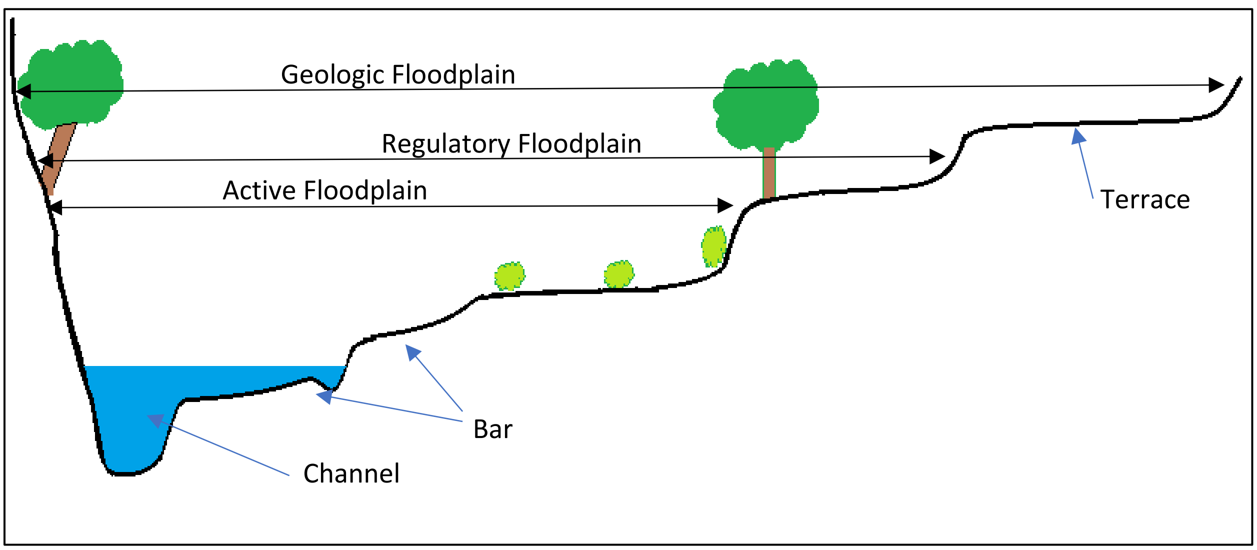

Figure 2. Elements of a river floodplain cross section.

- **Rapid**: A rapid is a fast-flowing and turbulent part of the course of river. Natural rapids may be caused by geologic features such as bedrock outcrops, canyon constrictions or expansions, channel bends, accumulations of coarse sediment at tributary mouths, or canyon slope processes. Rapids are also known as whitewater.

- **Riffle**: A riffle is a small, less significant rapid, typically with shallower water and a slightly steeper slope than adjacent parts of the river (Figure 3). A riffle often has shallow or exposed bed material such as gravel, cobbles, or boulders.
- **Pool**. A pool is an area of relatively deep, calm water located between rapids, with minimal flow velocity (Figure 3).
- **Run**. A run, or a glide,[7] is a reach of flowing water between riffles that typically has lower depths and higher velocities than a pool.

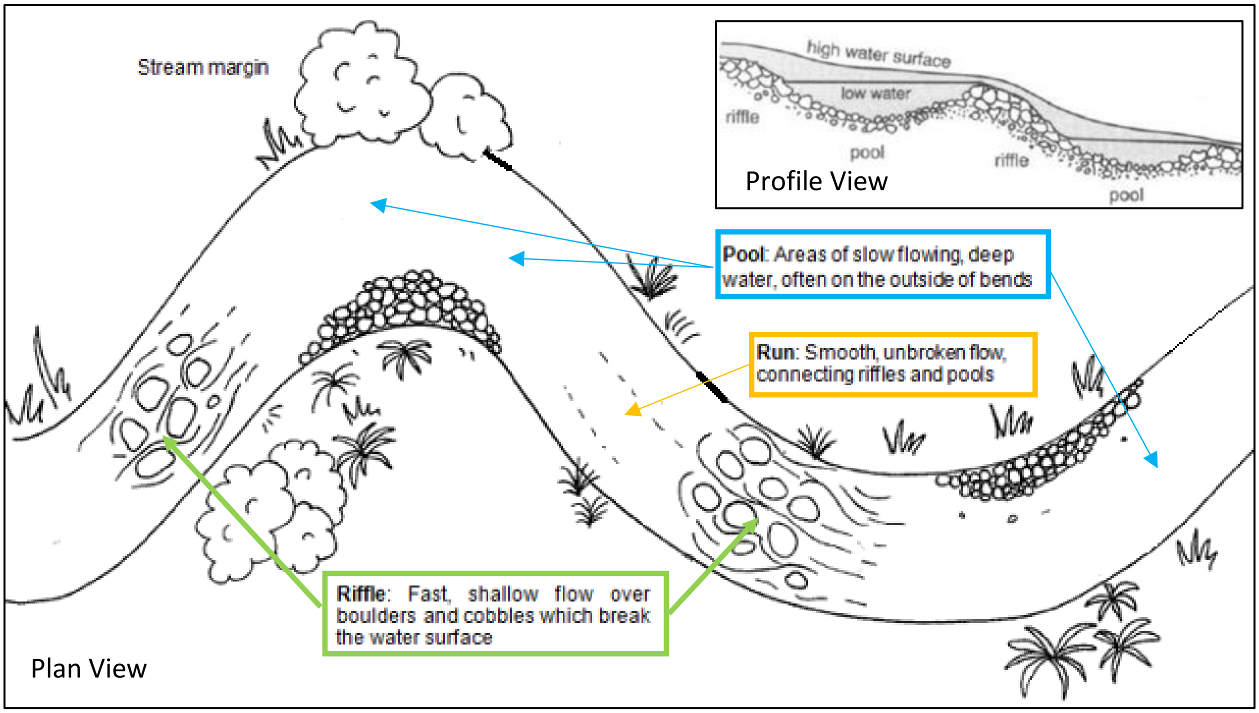

Figure 3. Elements of a river reach: pool, riffle, and run.

<u>Boating Terminology</u> (Refer to Figure 4)

- **Depth**. The depth of a boat is measured from the bottom of the boat to the top of the gunwales or sides of the boat. A boat's depth is not the same as a boat's draw.
- **Draw** or **Draft**: A boat's draw is the depth of water necessary to operate it without grounding. It is the distance from the water surface to the bottom of a boat floating on water. A boat's draw will increase with the weight of its load, i.e., a heavily loaded boat will draw more water than an empty boat. If a river is ordinarily shallower that a boat's draw, the river is not boatable for that type of boat at that flow rate.
- **Gunwales**. The gunwale is the top of the sides of an open boat, e.g., a canoe or rowboat.

[7] There are slight differences between runs and glides, but they are not important for navigability work.

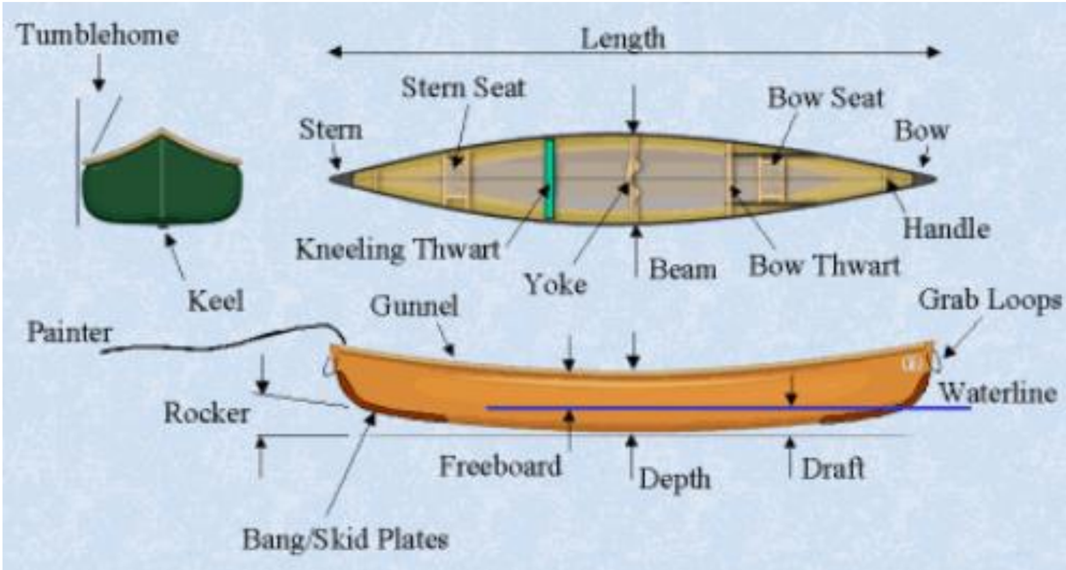

Figure 4. Illustration of boat terminology. ***A canoe is shown, but many terms apply to other small boat types.***

- **Flipping**. Small boats occasionally flip over due to pilot error, turbulent conditions, or river obstacles. While flipping a small boat certainly is not a desired outcome, neither is it usually a significant problem if the load is properly secured, the passengers outfitted with life preservers, and crew is trained to address the problem. Flipping large, heavily loaded boats has more serious consequences.
- **Swamping**. Swamping occurs when an open boat (not decked or covered) takes on water that must be pumped, bailed, or drained out of the boat to maintain optimum performance. Taking on water is a normal part of river boating that is easily addressed by experienced boat crews.
- **Pinning**. A boat pin occurs when it becomes trapped against a solid object (e.g., a mid-channel rock) and is held in place by the force of the river's current. Pinning a boat in deep, fast water can have serious consequences for the boat, the load, and the crew.
- **Portage**. A portage consists of carrying a boat and/or its cargo out of the river around a river obstruction or obstacle, or between two boatable water bodies. Portages can be done with loaded or unloaded boats. Most portages are done outside the river channel over land. Portaging is different than any of the following methods of passing an unboatable obstacle:
    - <u>Lining</u>: Guiding a pilotless boat past an obstacle using ropes held by persons on the shoreline – usually done at a challenging rapid that the boater has decided not to run.
    - <u>Dragging</u>: Pushing or pulling a boat while it is still in the river – usually done in shallow water over short distances without unloading the boat.
    - <u>Ghost-boating</u>: Sending a pilotless boat into the river – usually done at a simple, but challenging rapid with a well-secured load into a pool where the boat can be recovered.
- **Sweeper**: Sweepers are vegetation that overhangs into the boating channel so that its branches sweep the water surface (Figure 5) or the boaters that pass underneath. In some situations, sweepers can overturn small boats, especially if the current is swift and the boat is poorly handled.
- **Strainer**: A strainer is a solid obstacle (usually fallen trees) in a river that allows water to flow through it, but prevents passage of larger objects such as a boat, its contents, or the boat's former passengers, creating entrapment hazards (Figure 5).

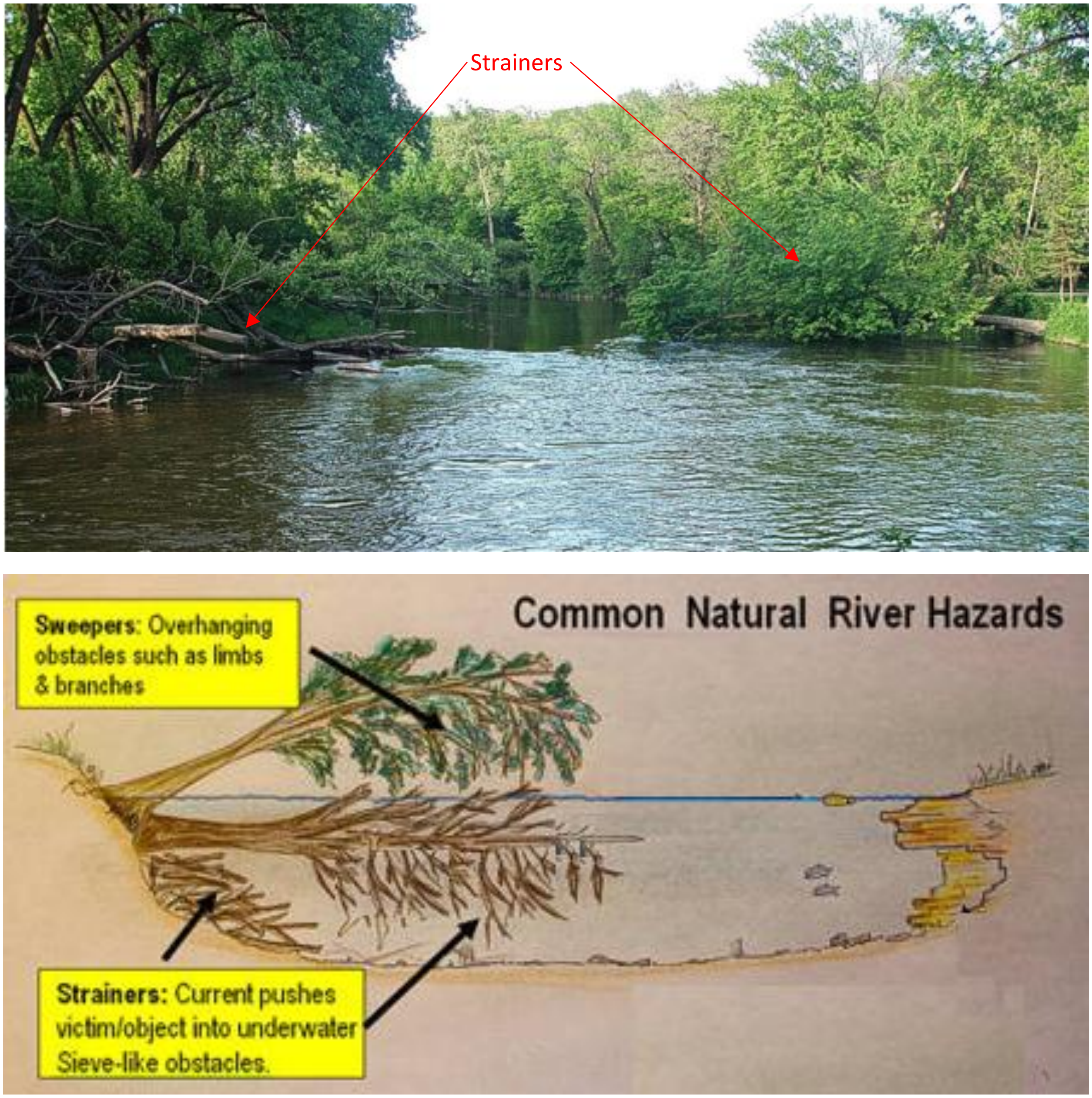

Figure 5. Photograph and Illustration of sweepers and strainers (photo & illustration by Tom Watson, www.paddling.net).

Hydrologic Terminology

- **Base Flow**. Base flow is the water carried by a river that is not the direct result of precipitation or unusual snowmelt, and consists mostly of discharge from the subsurface, such as springs, ground water, and seepage from the lands adjacent the river bottom. It is also called sustained runoff, dry weather runoff, or fair-weather runoff.
- **Flood**. A flood is a temporary rise in water level that inundates ordinarily dry land. This definition is sufficient for most navigability determinations, though the terms “temporary” and “ordinarily” leave some ambiguity (addressed in Chapter 7). Help with the ambiguity of the

words "temporary" and "ordinarily" can be found in guidance documents published by the US Army Corps of Engineers (USACE), which has established procedures for determining the ordinary high-water mark (cf, Wohl et. al. 2016; Lichvar & McColley, 2008). The differences between "flooding" and ordinary flow are discussed in more detail in Chapters 6 and 7 of this report.

- **Drought**. The term drought has specific scientific meanings, depending on the scientific discipline under consideration. For example, the US Geological Survey (USGS, undated) distinguishes between meteorological drought (abnormally dry weather), agricultural drought (shortage of precipitation that adversely affects crops), and hydrologic drought (below average water content in rivers). The Arizona Court of Appeals used the phrase "unusual drought," which suggests that they had something different (and less frequent) in mind than the USGS' "below average" definition for hydrologic drought. More detailed discussion of the term drought is provided in Chapter 7.
- **Erratic/Unpredictable**. Erratic means "deviating from what is ordinary or standard" or "acting, moving, or changing in ways that are not expected or usual; not consistent or regular."[8] Unpredictable means "not able to be foretold on the basis of observation, experience or scientific reason."[13] If a river's flow is so erratic or unpredictable that boating or log floating cannot or does not occur regularly, then practicably the river is not navigable for title purposes. However, no court navigability decisions have defined the words erratic or unpredictable, nor is there an established scientific definition of those terms. More detailed discussion of the relevance of erratic or unpredictable flow on navigability determinations is found in Chapter 7.

Navigability Terminology

- **Navigability/Boatability**. Navigability is a legal determination made by a judicial body, and is based in part on the ability to boat a river. Boatability refers to whether a river can be boated, which is an important, but not the only, component of a navigability determination.
- **Natural**. Lacking a statutory definition of "natural," the Arizona Court of Appeals in Winkleman v. ANSAC (2010) pointed to Black's Law Dictionary's definition that "natural" means "in accord with the regular course of things in the universe and without accidental or purposeful interference…, brought about by nature as opposed to artificial means…, untouched by civilization; wild." The term "natural" is discussed in detail in Chapters 3 and 6 of this report.
- **Ordinary**. The Arizona Court of Appeals in Winkelman v. ANSAC (2010) looked to Black's Law Dictionary for a definition of "ordinary" as: "occurring in the regular course of events; normal; usual." The Court specifically noted that ordinary excludes "drought" or "exceptional conditions in times of temporary high-water," i.e., floods. It also held that ordinary means the "conditions prevailing throughout the greater part of the year," implying that some high-water conditions are ordinary, rather than exceptional. The term "ordinary" is discussed in more detail in Chapters 4 and 7 of this report.
- **Ordinary High-water Mark**. The federal definition of "ordinary high-water mark" is "the line on the banks of a watercourse established by fluctuations of water and indicated by physical characteristics, such as a clear natural line impressed on the bank, shelving, changes in the

[8] Webster's Seventh New Collegiate Dictionary.

character of the soil, destruction of terrestrial vegetation or the presence of litter and debris, or by other appropriate means that consider the characteristics of the surrounding areas" (33 CFR 328.3(e)). The Arizona Revised Statutes (37-1101.6) uses the federal definition of the ordinary high-water mark, but adds that the "ordinary high-watermark does not mean the line reached by unusual floods," which is consistent with the 2010 Winkleman v. ANSAC decision.

- **Obstacles/Obstructions**. (See Chapter 3 for more discussion of obstacles and obstructions.)
    - Obstacles are river features that require that a boat be maneuvered around them. Obstacles include bars, rocks, bends, bank vegetation, islands, rapids, and riffles. Boats on rivers ordinarily and frequently pass obstacles.
    - Obstructions are river features which require portaging to pass. Common obstructions include a dry river bed, water shallower than a boat's draw or narrower than its width, or waterfalls. There are also human-built obstructions such as dams.

  The difference between obstacles and obstructions is in the difficulty of boating past the feature, but is also a function of the type of boat in use. For example, a long series of shallow riffles might be an obstruction to a steamboat, but only an obstacle to a trapper in a canoe.

Chapter 3:

Natural Physical Condition of a River

Lacking a statutory definition of "natural," the Arizona Court of Appeals in Winkleman v. ANSAC (2010) pointed to Black's Law Dictionary's definition that "natural" means:

> *"In accord with the regular course of things in the universe and without accidental or purposeful interference…, brought about by nature as opposed to artificial means…, untouched by civilization; wild."*

The court was addressing the question of whether irrigation diversions built and operated by the Hohokam civilization that occupied central Arizona along the lower Salt River for nearly 2,000 years created a situation in which the Statehood-era diversion dams built by early Euro-American settlers should be considered the ordinary and natural condition of the river. The court made it very clear that dams and diversions are built by humans, not by nature, and thus could not be the natural condition of the river, regardless of whether the dam builders were modern Euro-American settlers or "pre-historic" indigenous peoples. While the long history of human-built diversions may have left the river ordinarily depleted of flow for significant portions of its history, the federal test requires evaluation of the river in its ordinary *and* natural condition, not just its ordinary condition.

From a practical perspective, it may not be possible to precisely quantify or even observe the completely undisturbed, pre-human conditions of some rivers, particularly if factors such as human-induced climate change or potential impacts on the river by indigenous peoples prior to Euro-American settlement are included in the assessment. The Winkleman Court recognized this and allowed for a best-available evidence standard regarding human impacts on the river.[9] Nonetheless, the court-dictated goal of a navigability assessment is to identify the condition of the river absent any human impact. Issues related to describing and characterizing a river's natural navigability characteristics are discussed in this Chapter. Issues related to a river's natural flow rate are presented in Chapter 6.

Natural River Characteristics

To assess the natural condition of a river with respect to navigability, the following questions must be answered:

- Is the river currently in its natural condition? If the river is currently in a natural condition, then modern observations of the river are directly applicable to a navigability determination. In addition, if the river remains in a natural condition, evidence regarding some types of modern recreational boating may be relevant to a navigability determination.

- Has the river always been in a natural condition? If the river has recovered to a natural condition from a previous disturbed condition, then historical observations and information must be interpreted in light of the time when the river was disturbed versus when it was natural.

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[9] 224 Ariz. 230, 229 P.3d 242. [22] – "…the River could be considered to be in its natural condition after *many* of the Hohokam's diversions had ceased to affect the River, but before commencement of modern-era settlement and farming in the Salt River Valley…" (emphasis added).

- When was the river not in its natural condition? If the river is no longer in its natural condition, or was in a non-natural condition for some period of time, then it must be determined when and how humans altered it. Then, the historical record must be interpreted in light of the timing and physical characteristics of the human-caused changes. Furthermore, the nature of the human impacts must be understood to determine how to interpret pre- and post-alteration observations and river uses relative to navigability. If the river was altered prior to recorded history, then it will be necessary to reconstruct the natural condition using pre-historical information and/or geomorphic analyses.

- What are the natural river characteristics that relate to navigability? It is important to recognize that only river characteristics that relate to navigability need to be quantified. Some human-altered river characteristics, while important, may be not be substantive with respect to navigability. For example, extinction of a native aquatic species may be ecologically significant, but may have no discernable impact on the river's suitability for "trade or travel on water." Similarly, it is possible that certain large-scale, human-caused watershed changes such as deforestation or floodplain encroachment could have indirect, and possibly offsetting impacts on the river's depth or width, or that the stream corridor's unique geomorphology made it resistant to change, such that no substantive changes in the river's boatability characteristics have occurred due to those human activities. That is, it is necessary to document the types of change that have ***actually*** occurred to the river, rather than to simply identify human impacts that might have changed the river's characteristics.

Once a river's natural navigability characteristics have been determined, then it can be determined to what types of uses the river would have been susceptible. In addition, the historical record of boating, log floating, or other records of trade and travel on the river (or absence thereof) can be interpreted in light of the timing of when and how river characteristics were transformed from natural to non-natural conditions. For example, lack of a historical record of boating a river may be due to construction of diversion dams and reservoirs which diverted the natural river flow and created boating obstructions. Conversely, flow regulation and water storage releases from reservoirs may have made a river more conducive to boating than it would have been in its natural condition, giving a false impression of the river's navigability. Note that because most states have not yet established a standard for what type of boat is required to demonstrate navigability,[10] there is no universal suite of river characteristics that definitively equates to navigability. Similarly, there is no established threshold river depth that dictates a finding of navigable or non-navigable. However, the following natural river characteristics are most important for determining the boatability of a river:

- River Depth
- River Width
- Obstacles & Obstructions

Each of these characteristics are described in more detail below.

[10] Navigability decisions have been based in part on canoe use by fur trappers, inflatable rafts used for commercial recreation, wooden flat boats, or log floats, as well as based on larger river craft such as steamboats, barges, or sea-going vessels.

Natural River Depth

River depth is one of the most important characteristics for determining the boatability of a river. If the river's natural condition does not ordinarily have sufficient depths to support trade and travel on water (including floating logs), then it cannot be navigable. If adequate depths ordinarily exist, the river may be navigable.

While the "depth" of a river may at first appear to be a very simple concept that does not require definition or explanation, it is in fact a rather complicated concept that is difficult to accurately quantify with a single number. There is always variability in the depth of a natural river from place to place along the river profile due to naturally changing conditions at pools, runs, riffles, rapids, narrow and wide sections, sloughs, split channels, islands, scour holes, bank collapses, channel bends, and other natural features (Figure 6). Even at a single cross section of a river, the flow depth varies from zero at the bank lines to a maximum depth at some point (or multiple points) between the two banks.

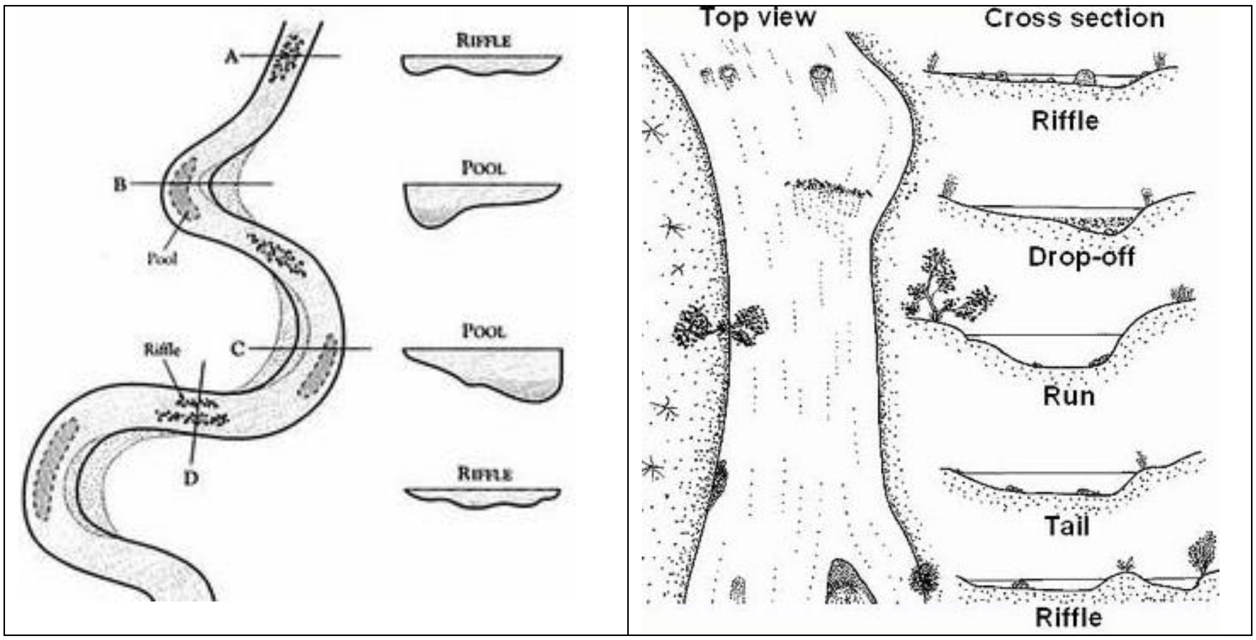


Figure 6. Example river profile showing typical variability in river depth along the channel.

This variability applies to both the average and maximum depths, two commonly used metrics for characterizing river depth (Figure 7). The average depth, by definition, underestimates the maximum depth. Since boating ordinarily occurs along the deepest part of the channel, the average depth may not give an accurate depiction of the boatability of a channel if its cross-sectional geometry is anything other than rectangular, i.e., most natural river channels. Similarly, the average depth of an entire river segment's length is a very crude, simplistic characterization of the actual depth experienced when boating a river, because the average integrates the depths of pools, riffles, runs, and other river features, and therefore may either overestimate (compared to a shallow riffle) or underestimate (compared to a pool) the actual depth at any given point along the segment. Therefore, characterizations of "river depth" based on a single observation point or cross section must be interpreted as rough, order-of-magnitude estimates with respect to actual boating conditions, particularly where only an average depth is reported. Because of the likelihood of over- or under-estimating river depth, it is very important to verify and evaluate depth estimates with thorough field investigations and by considering the types of boats that were, are, or could have been used on the river.[11]

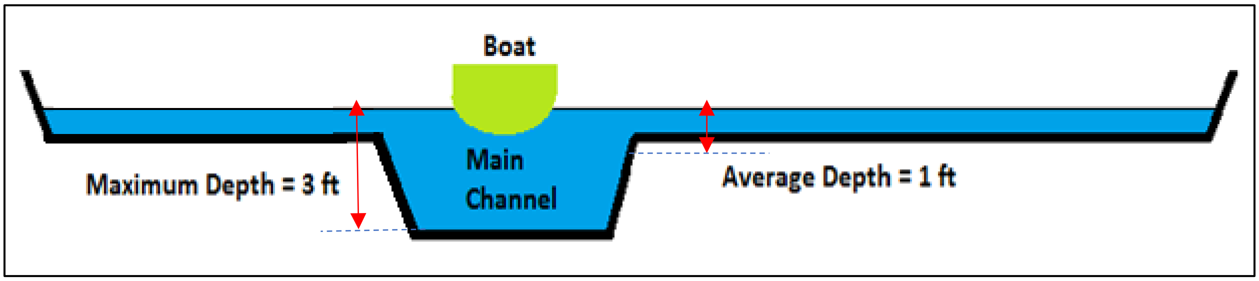


Figure 7. Example river cross section illustrating the difference between average & maximum depth.

The flow depth at any single point on a river also varies with time in at least two ways. First, as flow rates change seasonally or in response to runoff events, the river depth increases or decreases. An example of this phenomenon is shown in Figure 8, in which the water surfaces and channel cross section profiles on various dates were surveyed during the passage of the spring high flow period. On the left side of Figure 8, which tracks the rising limb of the high flow period, the channel bed elevations are scoured deeper as the water rises. Therefore, the change in water surface elevation is less than the change in maximum depth. The opposite trend is shown on the right side of the figure, as receding flows are coincident with a refilling of the scoured channel bed.

Therefore, it is important to provide depth estimates at flow rates that range from low flow (near drought conditions) up to the ordinary high-water mark, to properly document the ordinary range of depths in the river. Second, natural channels evolve with time as they meander, move laterally, scour and fill, degrade or aggrade, or cross geomorphic thresholds and change their dimensions. Therefore, the computed depth estimates at a single location should be presented along with estimates of their likely variability due to natural temporal changes in channel conditions appropriate for the type of river under consideration. This may be no more than a qualitative statement that the river type is subject to continual, periodic, or episodic channel shifting (e.g., a braided stream on a glacial outwash plain), or conversely that the river is likely to remain essentially unchanged over long time periods (e.g., a bedrock confined canyon stream).

[11] To account for the difficulty of representing flow depths over an entire river segment, some investigators boat the river in a craft of known draw, and report the number of "hits, stops, drags, and portages" in addition to providing information on measured depths at specific points along the reach. This information is also useful for assessing the difficulty of boating the river. See Sterin et. al (1998) and Whitaker et. al. (1993) for more information on this methodology.

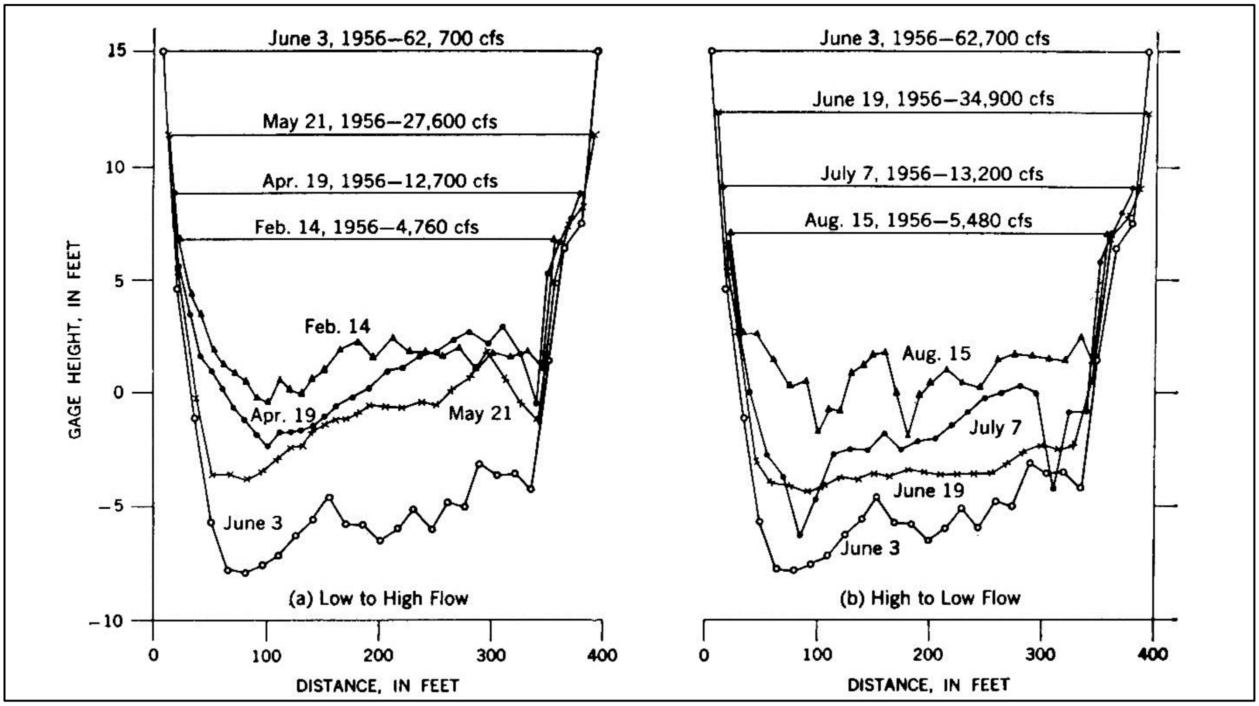


Figure 8. Temporal variation in measured river depth at a single location over a single season – Colorado River at Lees Ferry, Arizona (Leopold, Wolman & Miller, 1964).

In some cases, it is helpful to consider a minimum, or limiting, depth within a river segment. The limiting depth is a depth that is shallow enough to cause a boat to stop moving, and require it to be dragged, pushed, or portaged.[12] However, it is important to note that such stops do not preclude a navigability finding, though they certainly should be considered in the determination. When determining a limiting depth, it is important to characterize how frequently (i.e., ordinarily) the limiting depth occurs, both in time and space.[13]

That is, a limiting depth shallow enough to stop a boat is important if a significant portion of the river is at that depth in its ordinary condition. However, if the limiting depth only occurs in one location, in a shallow part of a cross section, could be avoided, or only during the dry season, then the occurrence of the limiting depth is less important to a navigability determination than if it occurred more frequently in time and space along the river segment.

Again, it is critical that any computed or modeled estimates of a limiting depth be verified relative to actual historical or modern boat use (Petrone et. al., in press). Actual boat use is a far more compelling means of demonstrating sufficient depths for boating, or lack thereof, than limiting depth estimates made using desktop methods that have not been verified in the field or by the historical record.

[12] A limiting depth should not be based on a single rock or other obstacle protruding from the streambed if the obstacle could be avoided and if a deeper boatable channel exists elsewhere in the cross section. A limiting depth assessment should presume that the boat captain is attentive and is reasonably skilled at avoiding shallow water, and has a working knowledge of the river.

[13] The United States Supreme Court (cf. The Montello, 1874; United States v. Utah, 1931) has found that navigability does not have to be without difficulty, and may include locations of shallow water that require occasional boat dragging or brief portages.

Limiting depth evaluations are only necessary if river depths are likely to be in the range of the draw of the boats being considered in the navigability determination. The minimum flow depths for a variety of common historical and modern small boats are shown Figure 9. Where flow depths are known to be ordinarily deeper than the draw of the boat types that define navigability, less detailed consideration regarding flow depths is required.

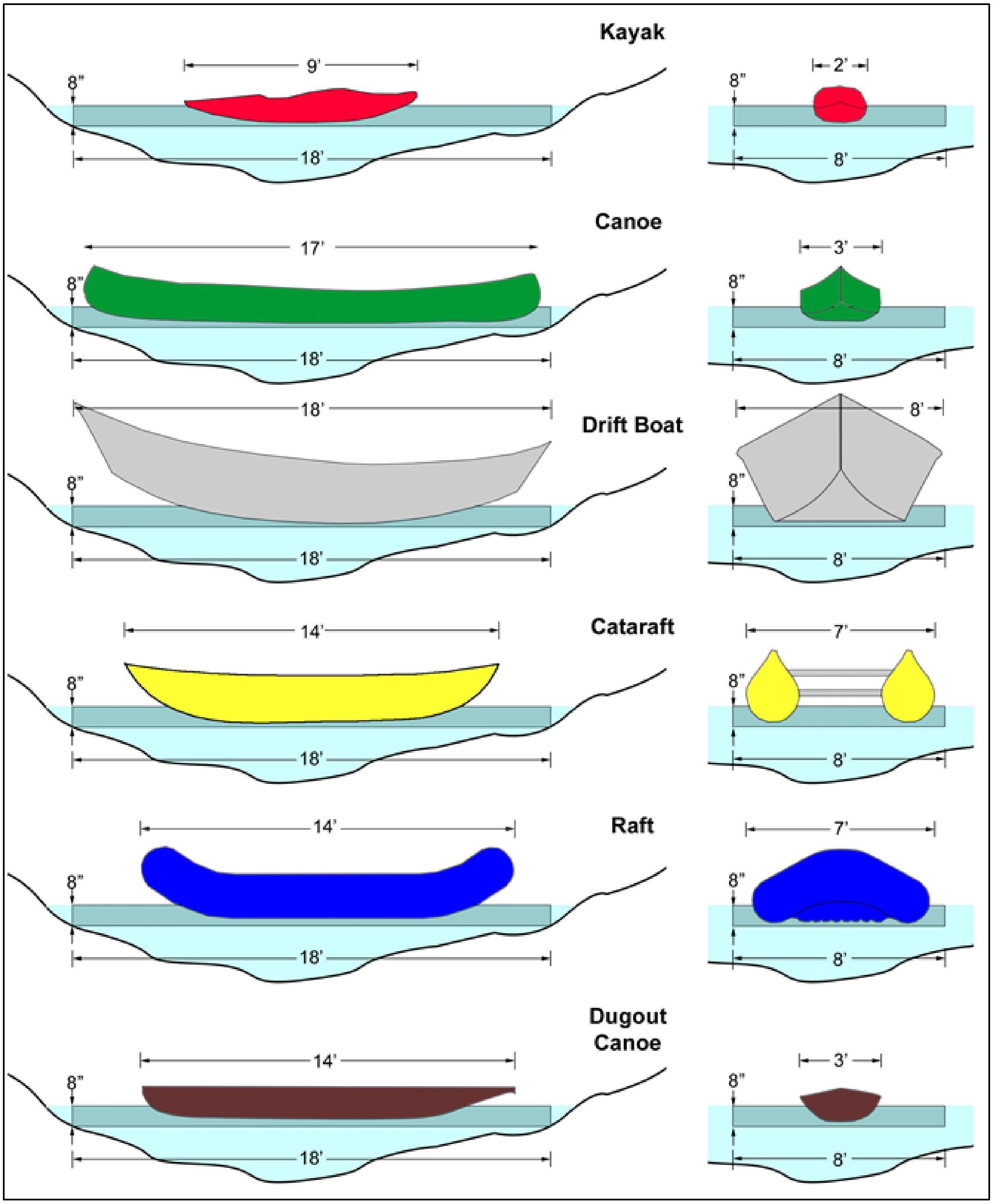


Figure 9. Required size, shape and clear channel needs for various historical & modern boat types (Shelby & Whitaker, 2010).

Therefore, for the purposes of assessing the ordinary and natural depth of a river, as much information as possible should be provided to characterize the natural variability of depth within the river segment.

Natural River Width

A river must be wide enough to allow boat passage. At minimum, this includes the width of the boat, as well as any extra width required to operate any oars, paddles, poles, or other means of propulsion.[14] In addition, there must be sufficient width to maneuver the boat around obstacles. The amount of extra river width required for boat maneuverability is a function of a boat's length, load, and design, as well as of river characteristics like the water velocity, bed materials, the types of obstacles in the river, and the skill of the boat captain. Like the river depth, the width of natural rivers usually varies along the length of a river segment and with time, for the same reasons listed above for the river depth.

In practice, river width usually is not the limiting factor for boating on natural rivers that are the subject of navigability studies, except when considering very wide or long boat types with low maneuverability, or when considering very small creeks and streams. Also, very narrow rivers may be more difficult to boat where overhanging vegetation or fallen trees create obstacles so dense and persistent over long portions of a river segment that they are difficult to pass, a situation that is more likely to occur if the low flow channel width is less than the height of trees growing on the river banks. The minimum flow widths for a variety of common historical and modern small boats were shown Figure 9.

Natural Obstacles and Obstructions

The presence of natural obstacles and obstructions are also important to a navigability determination, as they may inform on the types of boats that could be used and the difficulty of such use. <u>Obstacles</u> are river features that require maneuvering to avoid. Natural rivers always have obstacles, and their presence does not preclude a finding of navigability. One of the requisite skills of a boat captain is the ability to keep the boat within the boating channel and to maneuver around obstacles. <u>Obstructions</u> are river features which require a significant portage before continuing the trip. In some cases, an obstruction might end a boat trip. Some rivers have natural obstructions.

Whether a natural river feature is an obstacle or an obstruction depends on a variety of factors, such as the size of the feature, how frequently it occurs in the river segment, the flow rate, natural temporal changes in the river corridor characteristics, the type of boat considered, the type and weight of the load carried in the boat, the skill of the boat captain, and the level of difficulty and inconvenience that the boater is willing to tolerate. The evaluation of all of these factors relative to a river's boatability may go beyond the scope of a typical ordinary and natural condition assessment. For the purposes of the ordinary and natural condition assessment, it is usually sufficient to list and describe the types of obstacles and obstructions present, and document any known human-caused changes to them.

More detailed discussion of specific river obstacles and obstructions follows:

- Bars. Most natural rivers have bars of some type (Figure 10), either mid-channel (e.g., sand bars, braiding, transverse bars), and/or along the margins of the channel (e.g., lateral bars, seasonal beaches, etc.). Many rivers with bars are navigable, e.g., the Colorado River, the

[14] Note that oared or paddled boats can pass through narrow points by shipping their oars for brief periods.

Mississippi River. Bars are generally only an obstacle at low water, at the channel margins, or in shallow water near the banks, or near islands, and only if the bars are submerged at depths less than a boat’s draw. Bars would only be an obstruction if the entire river was shallow and the bars were so prevalent that no boatable channel could be found around and through the bars, a rare situation on most natural rivers, and one more likely affect large, deep-draft boats with poor maneuverability than small, low-draft boat types.

Figure 10. Photograph of sand bars in flowing rivers. (1) Left: Colorado River near Bullhead City, Arizona - submerged and exposed point and lateral bars, with easily identifiable boating channels (aerial photograph from Google Earth Pro), (2) Right: Cimarron River, Oklahoma – barely submerged, shallow sand bars that occupy much of the main channel and would be difficult to pass except in very shallow draft boats.

- Rocks. Mid-channel rocks large enough to be an obstacle to boating are found on some natural rivers (Figure 11), especially on rivers located in narrow bedrock canyons where rock falls into the river channel are more common, or where floods can transport large sediment clasts. Such rocks can stop a boat, or even damage it if they are struck with force, but ordinarily boat captains can read the river to avoid such obstacles, or they learn the location of such obstacles through experience. In some cases, mid-channel rocks could create constrictions or rapids that might inhibit passage of especially large boats with limited maneuverability.

Figure 11. Mid-channel rock (denoted by the arrow) fallen from the canyon walls with easily passable routes on either side, Boulder Narrows, Mile 19, Grand Canyon, Arizona. Photo by Tom Lohkamp, July 13, 2014.

- Bends. All natural rivers have bends of some kind. Consequently, very few river bends are considered obstacles or obstructions to boating. Some exceptions might include locations where the bends are particularly sharp (e.g., greater than 90 degrees), where they are caused by bedrock projecting into the boating channel, where they create a significant rapid, where velocities are high, or where they have eroded a vegetated bank and the fallen bank vegetation blocks the boating channel. Even in such cases, a competent boat captain in the right type of boat can maneuver around the bend and successfully boat the river bend with minimal difficulty.
- Bank Vegetation. On some small rivers, bank vegetation may overhang or fall into the boating channel and create sweepers or strainers that should be avoided when boating (Figure 5, Figure 12). Sweepers and strainers can create entrapment hazards or can overturn a small boat if the water is sufficiently deep and fast moving. In shallow or slow-moving water on wide rivers, sweepers and strainers are usually just a potential nuisance that is easily avoided by an attentive boater.

Figure 12. Photograph of easily avoidable sweeper/strainer on river left. Gila River below San Carlos Reservoir, February 2014.

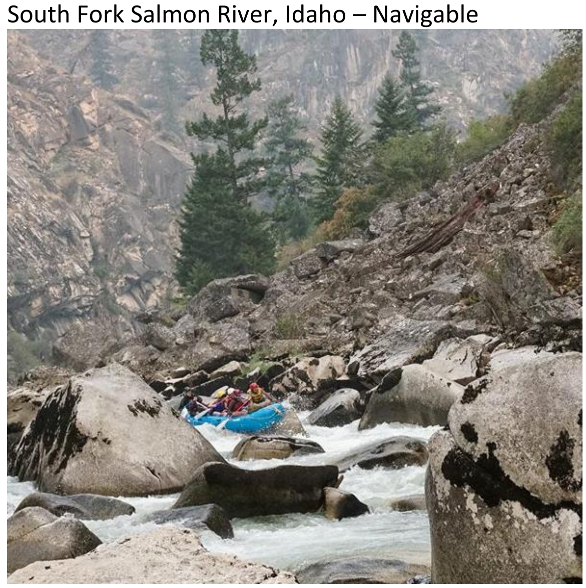
- Log Jams. Log jams can be obstacles or obstructions, depending on their size, location in the channel, and the type of boat being used. In some narrow canyons, log jams can temporarily dam the entire channel and create an obstruction to boating that may require a portage to pass. Log jams are more common in rivers where log-floating occurs,[15] or where the river banks or canyon walls are covered with woody vegetation. Some log jams form naturally as a result of floods that cause bank vegetation to be eroded and transported downstream. On most rivers, log jams are temporary features that are destroyed by subsequent floods or by decomposition of the woody material. However, some river reaches are prone to log jams due to their geometry and watershed characteristics, and thus are more likely to have log jams as part of their ordinary and natural condition.
- Ice Jams. Ice jams are obstructions to boating that occur in spring on some rivers in cold climates, but persist only until they melt or are swept away by high flows caused by snowmelt runoff. Melting of ice and dissipation of ice jams signals the onset of the open water season on many cold climate rivers. Because they occur outside the open water season, ice jams are usually of little importance to navigability assessments.
- Islands. Some natural rivers have islands that are obvious obstacles to boating (Figure 13), but that are usually passed without difficulty. The presence of an island does not preclude navigability, as many rivers found to be navigable have large or small islands (e.g., the Mississippi River, the Colorado River, etc.), some of which can be inundated at high flow and others which are permanently exposed above the water.

[15] Log jams caused by log floating or other human activity are not part of the river's natural condition.

Figure 13. Small, easily passable island on the Mosquito Fork, Alaska.

- Rapids. Many, but not all, natural rivers have rapids, including many that have been found navigable (**Table *1***, Weber River, Umpqua River, John Day River, many others). Some rapids are obstacles and some are obstructions, depending on the classification of the rapid and the type of boat in question. Most river rapids are classified using the International Scale, which goes from Class I to VI (**Table *1***). Class I to V rapids are all considered runnable, albeit with increasing difficulty and consequence. Class I and II rapids are considered runnable by novice boaters. Class III rapids are considered boatable with intermediate skills. Class IV and V rapids require advanced or expert skills. A Class VI rapid is considered unrunnable, and by definition is not boatable. If boaters begin to consistently run a Class VI rapid, it is downgraded to a Class V rapid. However, it is possible for any class of rapid to be an obstruction to some types of boats, such as large, deep draft, low maneuverability craft (e.g., barges) which are suitable only for deep, flat water.
- Riffles. Riffles are small rapids. Riffles occur on most natural rivers and generally are not considered obstructions to boating, except where flow depths are too shallow for a given boat type.

Table 1. International Rating Scale for Rapids		
Class	**Description**	**Examples**
Class I	Fast moving water with riffles and small waves. Few obstructions, all obvious and easily missed with little training. Risk to swimmers is slight; self-rescue is easy. This category includes most riffles.	Mosquito Fork, Alaska - Navigable  Unnamed rifle (Class I) – Photo by Jon Fuller
Class II: Novice	Straightforward rapids with wide, clear channels which are evident without scouting. Occasional maneuvering may be required, but rocks and medium-sized waves are easily missed by trained paddlers. Swimmers are seldom injured and group assistance, while helpful, is seldom needed.	Mosquito Fork, Alaska – Navigable  Unnamed rapid (Class II) – Photo by Doug Whitaker
Class III: Intermediate	Rapids with moderate, irregular waves which may be difficult to avoid and which can swamp an open canoe. Complex maneuvers in fast current and good boat control in tight passages or around ledges are often required; large waves or strainers may be present but are easily avoided. Strong eddies and powerful current effects can be found, particularly on large-volume rivers. scouting is advisable for inexperienced parties. Injuries while swimming are rare; self-rescue is usually easy but group assistance may be required to avoid long swims.	North Umpqua River, Oregon – Navigable  Lower Narrows (Class III) – Photo by Doug Whitaker

Table 1. International Rating Scale for Rapids		
Class	**Description**	**Examples**
Class IV: Advanced	Intense, powerful but predictable rapids requiring precise boat handling in turbulent water. Depending on the character of the river, it may feature large, unavoidable waves and holes or constricted passages demanding fast maneuvers under pressure. A fast, reliable eddy turn may be needed to initiate maneuvers, scout rapids, or rest. Rapids may require "must" moves above dangerous hazards. Scouting may be necessary the first time down. Risk of injury to swimmers is moderate to high, and water conditions may make self-rescue difficult. Group assistance for rescue is often essential but requires practiced skills.	Klamath River, Oregon – Navigable  Caldera Rapid (Class IV) – Photo by Doug Whitaker
Class V: Expert	Extremely long, obstructed, or very violent rapids which expose a paddler to added risk. Drops may contain large, unavoidable waves and holes or steep, congested chutes with complex, demanding routes. Rapids may continue for long distances between pools, demanding a high level of fitness. What eddies exist may be small, turbulent, or difficult to reach. At the high end of the scale, several of these factors may be combined. Scouting is recommended but may be difficult. Swims are dangerous, and rescue is often difficult even for experts. A very reliable Eskimo roll, proper equipment, extensive experience, and practiced rescue skills are essential.	South Fork Salmon River, Idaho – Navigable  Mule Kick Rapid (Class V) – Photo by Galen Barker
Class VI: Extreme	These runs have almost never been attempted and often exemplify the extremes of difficulty, unpredictability and danger. The consequences of errors are very severe and rescue may be impossible. For teams of experts only, at favorable water levels, after close personal inspection and taking all precautions. After a Class VI rapid has been run many times, its rating may be changed to Class 5	Great Falls Segment, Missouri River – Non-navigable 
Source of text: American Whitewater (*www.americanwhitewater.org*).		

- Dry River Bed. Obviously, a dry river bed is an obstruction to boating. Boating during irregular flows or floods on an ordinarily dry river does not meet the Daniel Ball test for navigability, and should not be considered as part of a navigability determination.
- Shallow Water. Similarly, shallow water is a boating obstruction if the flow depths are ordinarily shallower than the boat's draw. But because navigability law is not based on a specific boat type, nor does it require that a river be deep enough to boats for the entire year, it is necessary to quantify river depths relative to different boat types and uses, to the season of the year, and to specific river segments before making a navigability determination based on shallow water.
- Waterfalls. Waterfalls occur on some natural rivers, and can be obstructions to boating if they are high and steep enough to require a portage. Some river features that are called "falls" in boating guides are just steep, short, Class II to V rapids, rather than true waterfalls (Figure 14). Field investigation may be required to distinguish true waterfalls from misleadingly named rapids, and to determine whether the feature is an obstacle or an obstruction.

Figure 14. Waterfalls versus rapids misnamed as "falls." Clockwise from top left: (1) Verde Falls, Verde River, Arizona – a Class III-IV rapid (being run in an inflatable kayak), (2) Havasu Falls on Havasu Creek, Arizona – a true waterfall, (3) Mescal Falls, Salt River, Arizona - a Class II-III rapid (being run by a hard-shell kayak and a canoe).

- Beaver Dams. Beaver dams are found on some natural rivers. Some beaver dams are obstacles to boating, and some are obstructions, depending on the river and the type of boat being considered. Some beaver dams have a boatable sluice channel, do not span the entire river, or are low enough to easily slide a boat over, and thus do not impede some types of boating (Figure 15). In fact, beaver dams may raise upstream water levels, and detain floods in a manner that can make adjacent river reaches more boatable than they would be without the beaver dams. Others beaver dams require more complicated procedures for some boat types, such as unloading the boat and portaging around the dam. It is important to note that the presence of beaver in a river does not mean that there will be beaver dams. On many large rivers, rivers with sufficient depths, or rivers with large annual floods, beavers dwell in the banks and may not need to construct dams in the main channel to create favorable living conditions. On other rivers, beavers may construct dams or lodges on side channels or connected marshlands that have no impact on boating in the main channel. Therefore, it is important to carefully evaluate historical accounts of beaver populations on a river before assuming that the presence of beaver in a river indicates that beaver dams existed that were obstacles or obstructions to boating.

Figure 15. Boating Over a Beaver Dam without a portage.

At present, no court has established any firm threshold for the number, density, type, or level of difficulty of obstacles relative to finding a river navigable or non-navigable. Undoubtedly, every navigable river has some kind of obstacle, potential hazard, or other natural characteristic that requires skill or effort to boat around it. Courts have, however, ruled that navigable rivers may include some level of difficulty (United States v Utah, 1931; United States v Holt Bank, 1926), but also that some obstructions may render a specific river segment non-navigable (e.g., the Great Falls segment of the Missouri River, PPL Montana v. Montana, 2012). Therefore, it is necessary to describe and quantify the types of natural obstacles and obstructions that exist(ed) in the river when it was in its ordinary and natural condition.

Natural River Patterns

Natural rivers exist over a wide spectrum of shapes and sizes, and are often classified by their stream patterns, the most common of which are meandering,[16] braided, and straight (Figure 16). While rivers are often classified as having a single stream pattern category, rivers frequently have characteristics of multiple pattern types (Leopold & Wolman, 1957). In addition, the differences between the pattern types on natural rivers are transitional rather than distinct. That is, a river that is properly classified as meandering may have localized braiding, or some reaches of an otherwise braided river may have a single sinuous channel (Figure 18). With respect to navigability determinations, there is no stream pattern which has not been, or cannot be, found navigable.[17] Therefore, the existence of any particular stream pattern is not particularly relevant to a navigability determination. In addition, no specific stream pattern is necessarily indicative of human disturbance.[18]

On some rivers, the appearance of the channel pattern changes with the flow rate. Some rivers may be highly or partially braided at low flow, and have a single channel (or be less braided) at higher flows, e.g. the lower Colorado River in Arizona prior to human impacts on the river, or the Knik River in Alaska (Figure 17). Other rivers may have a single channel at low or moderate flows and become braided at increased flood stages, e.g., compound rivers such as the Salt and Gila Rivers (Figure 19). The degree of braiding is also influenced by the rate of sediment supply in the river, the river's velocity and stream power, and the ratio of normal flow rates to flood flow rates. Rivers with high velocities, high sediment loads, flood peaks much greater than their ordinary flow rates (high flood ratios), and steep slopes are more likely to experience braiding. With respect to navigability, braiding results in periodic changes in channel locations and depths that may alter the location of the boating channel and require a boat captain to periodically relearn the river. In general, braided rivers tend to have shallower average flow depths than meandering rivers at the same discharge, although it is important to evaluate the natural flow depth for each river individually, rather than rely on such generalizations.

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[16] A meandering river is defined as having a sinuosity of 1.5 or greater. Sinuosity is the ratio of the main channel length to the river corridor length, i.e., "curvier" rivers have higher sinuosity. River channels with sinuosity less than 1.5 are technically not meandering rivers, but are affected by similar processes of erosion and deposition on the outside and inside of channel bends, respectively.

[17] Some past navigability determinations in Arizona have inordinately focused on stream pattern classification, particularly on whether the river had braided channels, despite testimony from both sides that braided rivers can be navigable (Figure 17, Figure 18) as well as historical documentation showing that the navigable Colorado River was braided.

[18] Braiding or gullying can be a response to human activities such as over-grazing, in-stream mining, or deforestation, but both braided channels and gullied rivers occur naturally as well.

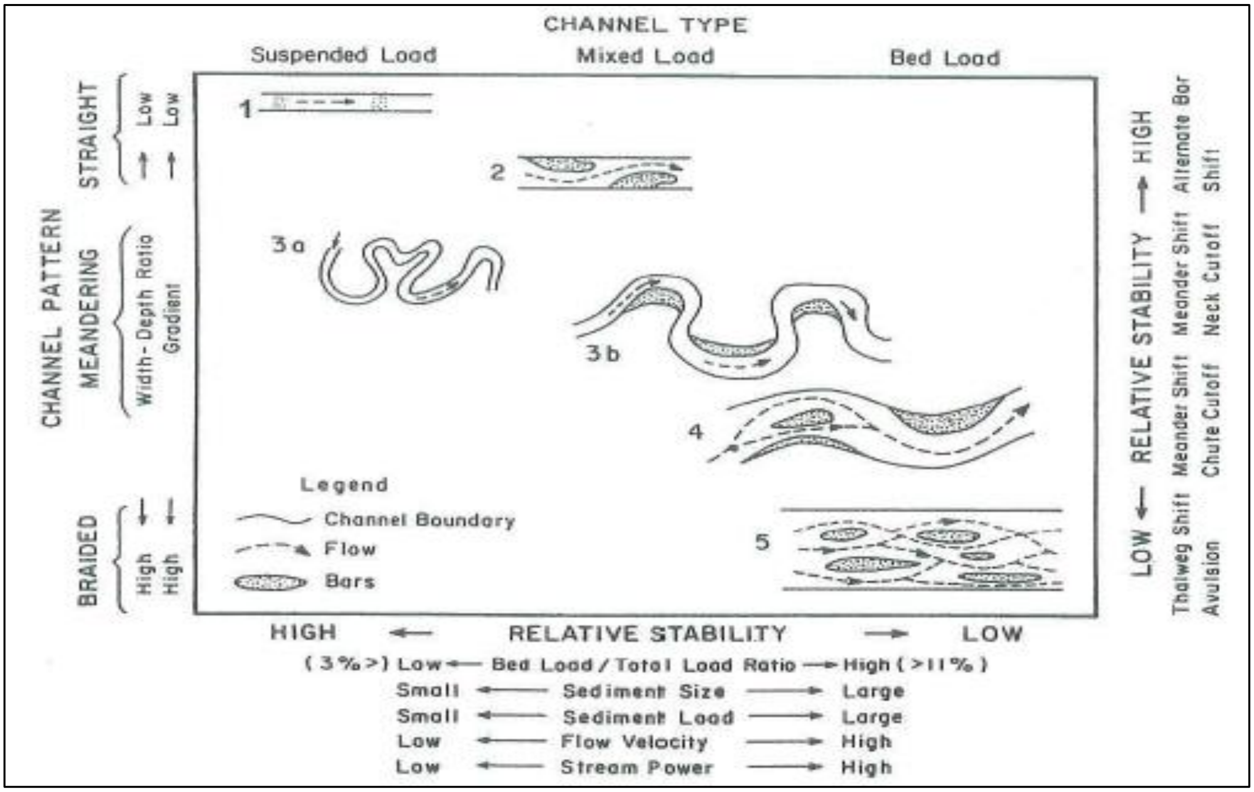

Figure 16. Typical Chart Showing Channel Patterns Relative to Slope and Sediment Load (Schumm, 1977).

Figure 17. Highly braided channels on the navigable Knik River, Alaska.

Figure 18. - Braided, meandering & sinuous channel reaches on the navigable Mosquito Fork, Alaska.

In addition to the most common stream pattern types – meandering, braided, and straight – the following types of stream patterns and types may also exist, and may have implications to a navigability determination:

- Compound Channels. Compound channels are characterized by a single, sinuous (or meandering) low-flow channel inset with a wider braided flood channel network (Figure 19). Lichvar & McColley (2008) call it the most common channel type in dry regions. The lower Salt River and portions of the Gila River in Arizona were classic examples of compound channel patterns (Graf, 1988). With respect to navigability, the following apply to compound channels:
    - The inset meandering low flow channel is of more importance to a navigability determination than the braided flood channel, since the inset, main or low flow channels convey the non-flood, i.e., ordinary, flows. Any non-flood boating would have occurred on the sinuous inset channel, rather than in the ordinarily dry flood channel.
    - The location of the main channel on a compound river system may change rapidly during large floods, but will be re-established with similar morphology to the pre-flood channel as flood stages recede and ordinary flows return. The morphology of the inset channel may continue to evolve over time, particularly in the years immediately following very large, system shaping floods (Burkham, 1972).
    - The ordinary high-water mark for a river with a compound channel pattern may incorporate much or all of the braided flood channel, well beyond the limits of the inset main channel, as described in USACE (Lichvar & McColley, 2008).

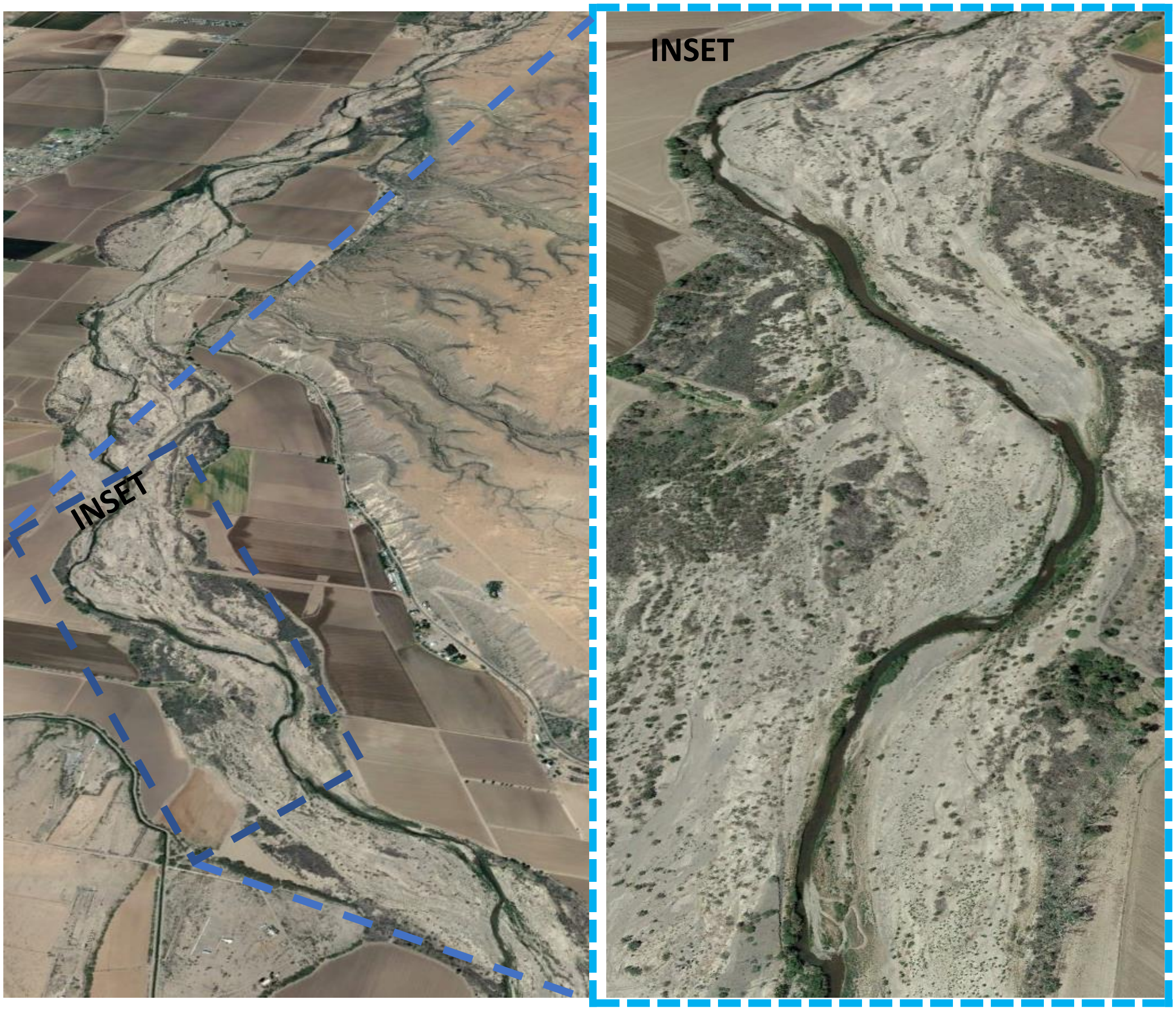

Figure 19. Aerial Photograph of Compound Channel Pattern, Gila River near Safford, Arizona. The flood channel (left) has a braided character, but is dry except during the largest floods. A closer view (right) reveals a sinuous single channel that conveys the ordinary flows that occur during non-flood periods

- Bedrock Confined Channels. The channel pattern of a river located in a narrow bedrock canyon may reflect its ancient geologic past more than its current flow regime. The meandering pattern of canyon sections of rivers like the San Juan River (Figure 20) or the Colorado River in Grand Canyon are imposed on the modern river by the surrounding geology and river's geologic past. The modern channel characteristics are influenced by the geologic setting and canyon sinuosity, but the navigability characteristics of the river are dictated more by modern flow rates inset within the broader, ancient geologic context. Therefore, the channel pattern should be described with respect to both the geologic influence (bedrock canyon morphology) and the boating channel (modern river).

Figure 20. Incised Bedrock Meanders on the San Juan River, Utah. Google Earth Pro image dated 3-18-2016.

- Split Channels. The occurrence of a split channel at a single location (Figure 21) does not necessarily make a river braided, even though the split channels are sometimes referred to as braids. As noted above, natural river channel patterns exist in a continuum, and elements of one type can often be found in another type (Leopold & Wolman, 1957). A correct stream pattern classification should consider the overall characteristics of the river system, rather than one or two points within a river segment. With respect to navigability determinations, the presence of a split channel means nothing definitive regarding the boatability of either split. In some cases, flow depths will be equivalent along either flow path. In other cases, one side or the other may be slightly or significantly deeper or wider, and the wider channel may be deeper than the narrow channel, or vice versa. Furthermore, the split channel may be either deeper or shallower than the upstream or downstream single channel. Usually, a competent boater can determine which channel is better for boating by reading the water, but sometimes experience is the truer teacher and the second boat through makes the better choice, after learning from the first.

Figure 21. Split Channels on the navigable lower Colorado River near Parker, Arizona.

- Incised Channels (Arroyos). Incised channels, often called arroyos in the Southwest, are disequilibrium channel forms caused when a stream crosses a geomorphic threshold and experiences geologically rapid lowering of the stream bed, creating a narrow channel inset below its former floodplain (Figure 22). Most arroyos are too small and too often dry to be considered navigable, but some of the larger river systems in the Southwest have experienced arroyo-forming incision events. With respect to a navigability determination, the following apply:
    - It is important to determine when the incision occurred relative to the date of Statehood, so that the ordinary and natural condition as of Statehood is considered in the determination. For many arroyo systems in Arizona, the timing of incision was coincident with the time of Statehood, making determining the timing both important and complex, since it may have occurred both before and after the date of statehood depending on the location of the river segment.

- It is also important to determine whether the cause(s) of the incision was the result of human activities or natural processes, or some combination of both. This will be no simple task, as the scientific literature is full of compelling arguments in both directions, sometimes for the same river systems.
- For rivers that incised naturally after Statehood, it will be necessary to piece together historical information, including any impacts on ordinary flow rates by the incision process, from which the pre-incision natural condition can be quantified. In most cases, this will be a difficult task.

Figure 22. Arroyo of the depleted San Pedro River, Arizona in summer dry season (photo by Joe Cook, AZGS).

- Meander Avulsion Channels. The natural process of meander avulsion is reasonably well documented in the literature (c.f., Slingerland & Smith, 1998; 2004). Meander avulsions occur as the meandering river erodes laterally to the point where it intercepts the next bend of the river, forming a new cutoff channel, abandoning and isolating the former river path as an oxbow lake which eventually becomes disconnected to the main channel of the river (Figure 23).

  With respect to navigability, the timing of the avulsion is important since public ownership of the streambed does not move with an avulsive channel change. Therefore, if the avulsion was natural and occurred prior to the date of Statehood, the conveyance of ownership would be based on the river's boundaries on the date of Statehood. However, if a natural avulsion occurred after the date of Statehood, the boundary of the sovereign land would remain along the former river channel (the oxbow lake) rather than the new cutoff channel.[19]

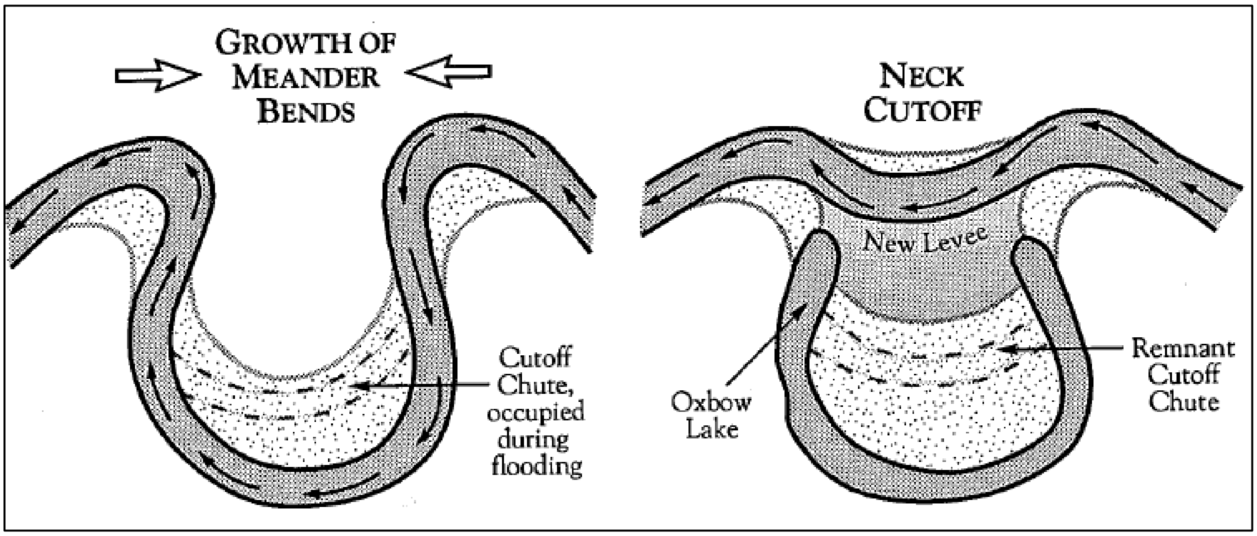

Figure 23. Illustration of the formation of a meander avulsion channel (from Mount, 1995).

- Alluvial Fans. Alluvial fans are aggrading landforms caused by net deposition of sediment where streams leave a confined channel corridor such as a mountain canyon, and spread out over a less confined alluvial surface. The channels on active alluvial fans periodically avulse from one part of the fan surface to another. In Arizona, there are no perennial streams on active alluvial fans, so the landform has little relevance to navigability determinations. In other states such as Alaska, streams on active alluvial fans may be perennial, but many of them tend to be too small or too steep for many kinds of boating. Should a boatable or navigable stream be found on an active alluvial fan, identifying the ownership boundaries on an avulsive system would be challenging. Detailed evaluation of ordinary and natural condition of a boatable stream on an active alluvial fan for navigability purposes is beyond the scope of this report.

[19] The same principle applies to most human-caused changes in river location, which are considered avulsions. Public ownership moves with the river, unless the change is avulsive. However, if the avulsive change was solely human-caused and occurred prior to Statehood, then presumably the natural (pre-change) river boundaries would dictate since the federal to state ownership transfer should be based on the ordinary and natural condition (without human impact) of the river.

- Deltas. Deltas are naturally occurring, aggrading landforms formed where a river flows into a static water body such as a lake or ocean. The movement of the river channel(s) on a delta is caused by sediment deposition, and mimics the avulsive processes on active alluvial fans. Many rivers with large, complex, active delta systems have been found navigable (e.g., Mississippi River). With respect to navigability determinations, the following apply:
  - Multiple Channels. Rivers crossing deltas often split into two or more multiple channels, sometimes with complex interconnected distributary channel patterns that shift and change with time, sometimes making boating more difficult as the location of the boatable channel(s) periodically changes.
  - Avulsions. Some of the channel changes on a delta may be avulsive. In such cases, the timing relative to Statehood and nature of the change must be deciphered to determine the location of the sovereign land boundaries.
  - Ordinary High-water Mark. On some river deltas, the ordinary high-water mark may incorporate the entire delta and all the historical and existing flow paths, as well as some of the adjacent lowlands, making the determination of avulsion timing and avulsive versus accretive changes moot with respect to the location of sovereign lands. Therefore, determining the ordinary high-water mark as the first step may circumvent any need to establish a detailed timeline of channel change on the delta. For other deltas, the lands between deltaic channels may have upland characteristics and would probably be above the ordinary high-water mark and thus outside the sovereign lands.

It is important to recognize that because stream pattern classification systems were not developed specifically to support navigability determinations, any published river pattern classification for a specific river should be interpreted in light of the publication's purpose rather than as an interpretation of the river's susceptibility to boating. For example, portions of the modern Gila River in Arizona could be appropriately described as a highly braided, ephemeral channel system for a fluvial geomorphology study of the overall river's response to large floods. That the river once had a perennial, sinuous channel inset within a braided flood channel might not be relevant for the purposes of a flood response or an erosion hazard delineation study, but would be highly informative for a determination of navigability for the portion of the river corridor that might be susceptible to various types of boating. Therefore, it may be necessary to carefully interpret stream classifications done for other purposes before applying them to a navigability study and drawing conclusions about potential navigability from the stream pattern classification.

Natural River Processes

Natural rivers are not static landforms, but instead are continually changing. Natural rivers change according to processes of steady state or dynamic equilibrium. For rivers in dynamic equilibrium, the overall form and function of the river remains the same, although the boundaries and locations of specific river features may change with time. For example, the force of water flowing along the river bed may cause sand on the stream bed to be swept downstream, which is a process of erosion. If the stream is in steady state equilibrium, the bed material lost to erosion is immediately or eventually replaced by sediment transported from upstream. The channel bed elevation may change slightly in response to fluctuations in the upstream and downstream sediment transport rates, but the overall shape of the channel hovers around an average, or equilibrium, condition which is essentially unchanged. Other natural river changes can be progressive, creating directional change, but are usually balanced by opposing processes that work to maintain the river's state of dynamic equilibrium. For example, a meandering river may erode the outside of river bend causing the location of the bank to migrate in one direction with time, but the river simultaneously deposits material on the inside of the bend, maintaining the overall shape and pattern of the channel when considered on a reach-wide basis.

Therefore, evidence of channel change processes should be expected on natural rivers. Some of the more common natural river processes include the following:

- Meandering. Meandering is a channel process, as well as a channel pattern. On meandering river, the channels progressively erode sediment from the outside of river bends and deposit sediment on the insides of bends (Figure 24). Over the long term, these progressive processes cause the river's meanders to move within the river's floodplain, changing the alignment of the main channel. With respect to navigability, meandering causes local channel depths and widths, the locations of bars, shallow water, and the position of the boating channel to change continually, requiring boat captains to periodically relearn how to most efficiently boat the river. Occasionally, channel changes due to meandering will cause boats to ground, get temporarily stuck, or even be damaged. However, many meandering rivers have been found navigable (e.g., the Mississippi River), so the existence of meandering processes does not preclude a navigability finding.

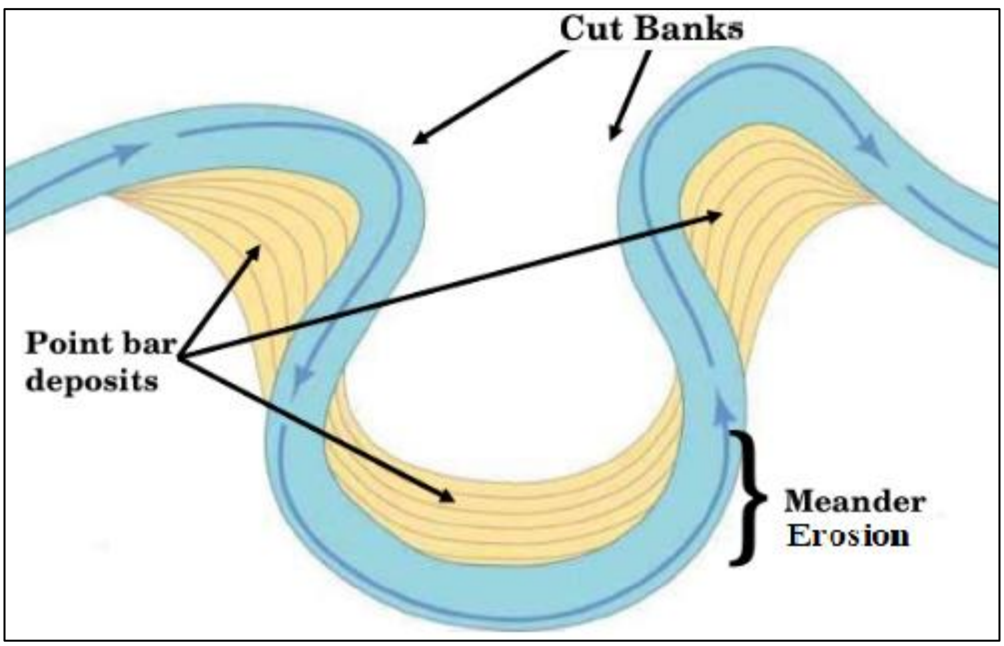

Figure 24. Illustration of meander erosion and deposition processes.

- Braiding. Braiding is a channel process, as well as a channel pattern (Figure 25). Braiding is defined as a process that causes channels to divide and rejoin around recently deposited or scoured river sediment. Rivers that experience natural braiding processes have been found navigable (e.g., Knik River, lower Colorado River, Delta River, Yukon River), so the existence of braiding processes does not preclude a navigability finding.

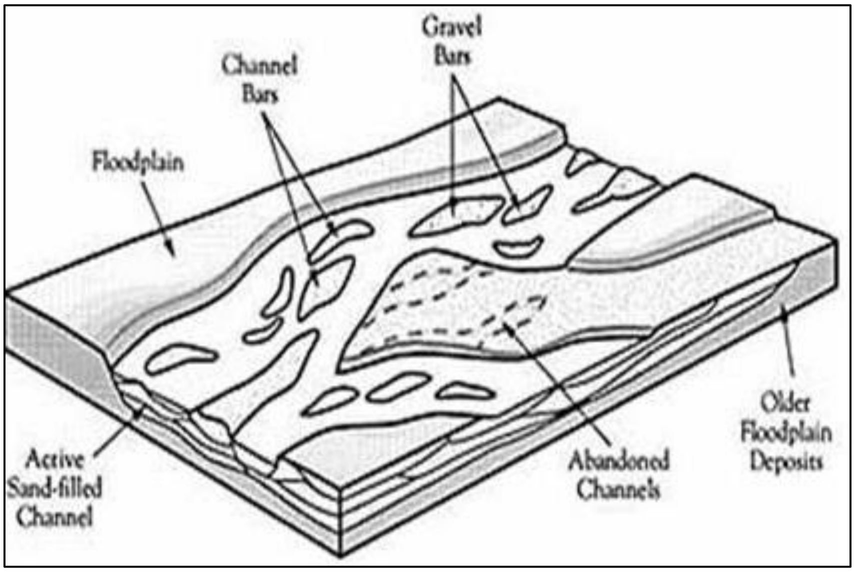

Figure 25. Illustration of Braiding Erosion Processes.

- Bank Erosion. Bank erosion, or lateral erosion, is a generic process defined as removal by any process of river bank material by flowing water (Figure 26). Bank erosion can occur by meandering, braiding, or any number of other processes that remove bank material. Bank erosion results in a widening of the main channel, which can result in a lower average depth over the short term if there is no compensatory deposition in another part of the channel. However, on natural streams, normal flows would restore the river's natural equilibrium geometry over time. Bank erosion can occur regionally by meandering or braiding stream processes, or locally at a single point on the river due to local flow velocities that exceed the bank's resistive strength. While bank erosion frequently occurs during large floods, it also may occur on a smaller scale during ordinary flow conditions. With respect to navigability, bank erosion sometimes causes bank vegetation or large sediment particles to fall into the boating channel, which in some circumstances may create temporary obstacles for boats. This is more of a factor on very small rivers with narrow widths. All natural rivers experience some level of bank erosion, so the occurrence of bank erosion does not preclude a navigability finding unless it can be shown that the bank erosion was so pervasive that it somehow ordinarily prevented navigation. However, rivers known for significant, frequent bank erosion (Colorado River, Knik River) have been found navigable, so the level of bank erosion that would be required to preclude navigability is yet undetermined.

Figure 26. Bank Erosion on Lower Salt River (left) and Colorado River (right).

- Scour. Scour, or vertical erosion, is defined as removal of bed material by flowing water in a river (Figure 8). Scour can occur naturally in the active channel or floodplain of the river. Scour may occur at a specific location within a river cross section (local scour), or may occur over the length of a river reach (general scour). Scour may be temporary (flood scour), filling back in on the receding limb of a flood hydrograph, or may persist long after a flood. Long-term progressive reach-wide scour (long-term scour) that lowers the stream bed elevation over time is called channel degradation. Scour occurs most often during high flows or in floods when the stream has sufficient power to move the river's bed material and transport it downstream. All natural rivers experience some level of scour, so the presence of scour does not preclude a navigability finding.

- Sediment Deposition. Sediment on the beds of natural rivers is in constant motion. Sediment is deposited locally in areas of lower velocities and eroded and transported from areas with higher velocities, resulting in the formation and removal of bars, beaches, and banks over time. River that experience net sediment deposition over time are called aggrading streams, and are more likely to experience braiding or avulsive channel processes. All natural rivers experience some level of periodic and continual sediment deposition, so the presence of depositional processes in a river does not preclude a navigability finding.

- Tributary Deposition. A common location of sediment deposition on rivers is at the mouths of tributaries (Figure 27). Tributaries are often steeper and/or more confined than the main stem river and thus may carry higher sediment loads with larger clasts that are more difficult for the main stem river to move. In addition, the tributaries often experience floods at different times than the main stem river. As a result, deposits of sediment are often found at tributary confluences. These deposits can temporarily obstruct or narrow the main channel, form rapids, or change the location of the main channel in ways that could alter the navigability characteristics of the river. Pearthree (1982) identified a cyclical process of tributary sediment deposition and main stem flood erosion that applies to many rivers. With respect to navigability, sediment deposits at the mouths of tributaries can create rapids that may be obstacles to boating, can narrow the boating channel, or in some cases temporarily block the main stem creating an unboatable obstruction. Tributary deposition is not an unusual process, and many rivers with significant tributary sediment deposits have been found navigable (Colorado River, Gulkana River, Weber River).

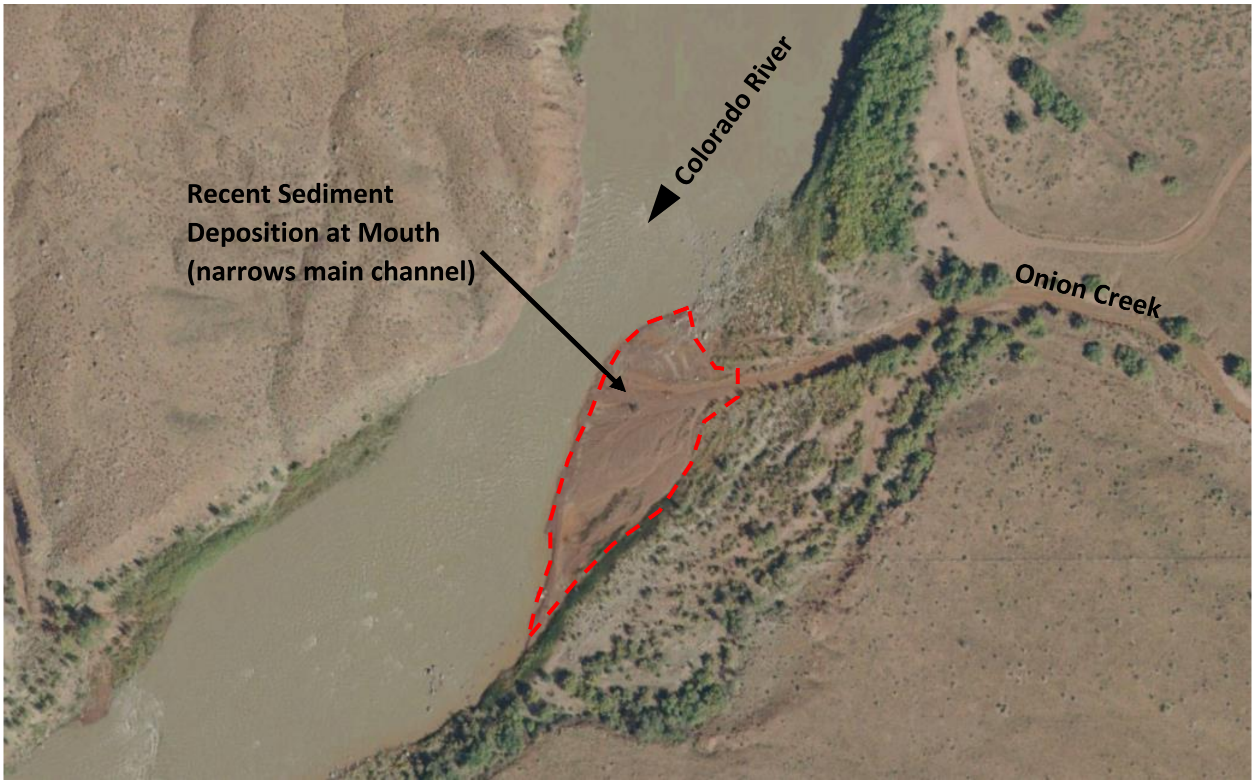

Figure 27. Tributary deposition at the mouth of Onion Creek, Colorado River near Moab, UT. Google Earth Pro 5/9/2003.

- Avulsions. An avulsion is defined as a sudden relocation of a river channel to another part of the floodplain. Avulsions occur naturally on meandering (meander cutoffs, Figure 23) and braided rivers, and are also common on aggrading streams. With respect to navigability, avulsive channel changes result in a new channel which typically has different characteristics than the pre-avulsion channel, and must therefore be re-learned by a boat captain. However, with time, the avulsive channels usually adopt the characteristics of rest of the river, making them a non-ordinary condition that may not be relevant to a navigability determination depending on the rate of recovery and permanence of the feature. Rivers that occasionally experience avulsions have been found navigable, so the presence of avulsion processes on a river does not preclude a navigability finding (Mississippi River, Knik River, Colorado River).

- Floods. Floods are flows that exceed the ordinary high-water mark of the river (See Chapter 7). Floods are relatively passive on some rivers, and are the primary change agent on others. On some rivers, floods can completely alter the location of the pre-flood boating channel, in some cases moving it thousands of feet across a floodplain and, in some cases, temporarily changing its geometry (Figure 28).[20] However, on natural rivers, the return of ordinary, non-flood flow rates will usually result in the restoration of the stream's natural equilibrium channel geometry.

[20] Note that the flood-caused changes in channel geometry could make the river either more or less boatable.

The rate of restoration of pre-flood channel conditions is a function of duration and volume of the ordinary flow rates, the size and characteristics of the sediments in the bed and banks of the post-flood channel, and the degree of disturbance that occurred during the flood. With respect to navigability, while floods are natural, they are not ordinary. The degree to which non-ordinary flood impacts on the post-flood channel geometry are relevant to a navigability determination has not yet been determined by a court.[21] However, rivers that experience major channel changes during floods have been found navigable (e.g., lower Colorado River, Knik River), so the occurrence of channel altering floods does not preclude a navigability finding. The relevance of floods to navigability determinations is discussed in more detail in Chapter 7.

Figure 28. Pre- and Post-Flood Channel Changes Along the Santa Clara River after the January 2005 flood.

Although rivers are constantly changing by natural processes, the pace and scale of change varies between rivers depending on a variety of natural and anthropogenic factors. However, the pace of natural channel change rarely, if ever, affects the boatability of river because the ordinary pace of natural channel change, even for fastest natural river processes, is much slower than the pace of a boat

[21] See Chapter 9, Case History #3: Gila River for more discussion of flood impacts on a river's ordinary condition.

using the river.[22] From the perspective of a boater, the fact that a channel bank has eroded during a recent flood or that the channel is now located in a different part of the floodplain compared to the last trip on the river is irrelevant if the river's dynamic equilibrium condition and geometry is preserved, i.e., the depth, width and obstacles in the boating channel are substantively unchanged. Some dramatic changes in river location due to avulsions or massive floods may have implications to the difficulty of boating (i.e., the river looks unfamiliar, the locations of obstacles must be relearned, a previous landing/launching spot may be further from the boating channel, etc.), but will rarely change whether the river segment is able to be boated unless a geomorphic threshold was crossed and there was a permanent change in the dynamic equilibrium of the river. Even in such (rather rare) cases, the change would not necessarily result in less boatable conditions, and might in fact improve boatability.

It could be argued that massive, natural floods could alter river morphology in a way that could render portions of a river unboatable, or at least make that river segment more difficult to boat immediately after the flood receded. Such changes would need to be carefully evaluated on a case-by-case basis to determine if the changes deteriorated or improved boating conditions in the river. It is not a given that the flood-eroded channel would necessarily be more difficult to boat. Furthermore, it is likely that a court would need to untangle the question of whether flood-induced channel change represented the "ordinary" condition of the river, or whether it constituted an extraordinary or unusual condition and was therefore irrelevant to a navigability determination. For the scientist working to provide technical information to a court regarding such a change, it would be necessary to characterize the extent of the change, the frequency of such changes over the long term, any anthropomorphic factors that may have contributed to the change, and the rate of recovery of the boating channel to the "ordinary" condition. For states where the date of Statehood pre-dates the availability of aerial photography and detailed topographic mapping, it is unlikely that sufficient data exist from which to answer such questions with great confidence. Finally, it is useful to recall that some rivers known to experience significant channel changes in response to floods have been found navigable (lower Colorado River, Knik River, etc.).

Since many types of channel changes occur naturally, and many natural rivers have been found navigable, the mere presence of historical channel change means little for a navigability determination and does not necessarily mean the river is not in a natural condition.

Human Disturbance of Natural River Conditions

Distinguishing natural channel change from human-induced channel change is a key component of assessing the ordinary and natural condition of a river. Humans can affect the natural condition of a river either directly or indirectly. A direct impact on the river would include anything that physically alters a river's boating channel, e.g., channelization or in-stream mining. An indirect impact would include any human activity that occurs outside the boating channel that results in a physical change to the boating condition, e.g., deforestation or over-grazing of a watershed, or results in channel changes outside the footprint of the impact itself. Some human activities have both direct and indirect impacts, e.g., construction of a major dam that not only alters the river channel at the dam and reservoir sites, but also may change flow rates in a manner that changes the geometry of the boating channel for some

[22] The rate of channel change during a flood may be quite fast. However, boating during floods is often dangerous and is typically avoided. More importantly, floods are outside the range of the ordinary condition of a river and thus are irrelevant for a navigability determination.

distance downstream of the dam. Procedures recommended for distinguishing the natural river condition from the human-impacted physical condition of the river are described in Chapter 5. Human impacts on a river's flow rate are discussed in Chapter 6.

The following are some of the more common human activities that may directly impact the physical condition of a river, most of which also have indirect impacts on the river:

- Dams
- Reservoirs
- Diversions (Irrigation, Water Transfers)
- In-Stream Mining
- Channelization
- Levees
- Road Crossings (Bridges, Culverts, At-Grade)
- Bank Stabilization/Erosion Control
- Encroachment (Development, Roads, Railways)
- Navigation Structures (Locks, etc.)
- Dredging[23]
- Logging/Removal of Riparian Vegetation
- Grazing in the Active Channel

The following are some of the more common human activities that may indirectly impact the physical condition of a river:

- Deforestation
- Over-Grazing
- Urbanization
- Land Use Change
- Human Induced Climate Change
- Loss of Wetlands
- Ground Water Withdrawal
- Land Subsidence
- Consumptive Water Use
- Irrigation Return Flows
- Discharge of Treated Effluent
- Flow Regulation
- Exotic & Invasive Species

If there is evidence that any of the human activities listed above have occurred in the channel or watershed, some level of analysis is required to determine if the river is or was in its natural condition. Some of the expected channel responses to the human activities listed above are listed in Table 2.

[23] Dredging is a special case. Some courts have found that dredging to improve or allow navigation may be considered differently than other human impacts. However, discussion of the legal relevance of such decisions is beyond the scope of this report.

Table 2. Expected Direct and Indirect River Responses to Human Activities with Respect to Navigability Characteristics			
Human Activity	*****	**Expected Direct Response**	**Expected Indirect Response**
Dams		Creates boating obstruction at dam structure. Creates upstream reservoir. Alters downstream flow rates from natural condition – may eliminate floods or droughts, decrease flood peaks, extend duration of flood hydrographs, and/or raise dry season flow rates. Flow depths and widths change with altered flow rates.	Downstream channel changes possible due to altered flow rates (ordinary flow, flood flows) and sediment supply. Changes may include increased long-term scour, channel narrowing/deepening, reduced meandering, bed armoring. Altered flow rates may induce changes in bank and floodplain vegetation. Loss of flood peaks may increase the number of strainers and sweepers in the boating channels, lead to narrowing of active channel, and increase impacts of tributary sediment deposition in main channel.
Reservoirs		Submerges river channel under reservoir. Induces delta sedimentation near upstream end of reservoir.	Water storage changes downstream flow and sedimentation rates. See responses to Dams above.
Flow Regulation		Changes flow seasonality - increases flows in low flow season, may decrease flow in high flow season.	Main channel geometry may change in response to new flow regime. Change in flow seasonality and loss of floods may change riparian vegetation, e.g., induce invasive species.
Diversions (Irrigation, Water Supply, Inter-Basin Water Transfers)		Diversion structure may be boating obstacle or obstruction. Decreased flow rates, particularly at ordinary flow rates. Decreased flow depth & width downstream of diversion out. Increased flow depth & width downstream of transfer in. Local sediment deposition upstream of in-stream structures. Scour downstream of in-stream structures. Channel altering maintenance activities in boating channel near diversion structures.	Channel geometry may change to reflect new flow regime. Low flow or boating channel may be obscured. Flood erosion & impacts may persist for longer periods. River training actions often used to keep channel at diversion structures.
Navigation Structures (Locks)		Improves navigation around obstructions.	Sediment maintenance activities may change natural channel geometry.
Dredging		Improves navigation by deepening the channel.	Increases in velocity, downstream sedimentation.
In-Stream Mining		Mining pit or structures may be boating obstruction. Changes natural channel geometry in mining footprint. Floodplain mining may capture and relocate the main channel.	Headcutting/tailcutting in channel up/downstream of mine. Up/downstream reaches may armor (coarse bed sediment), increasing lateral erosion, and/or change flow depths. Placer mining or dumping of mine tailings can lead to excess sedimentation on the main stem channel.
Channelization, Levees, Bank Stabilization & Erosion Control		Narrowing of channel or floodplain may increase flow velocity. Increased scour (deepening) near protected channel banks. May increase downstream flood peaks due to storage loss.	Changes natural river processes of meandering, braiding. Sediment deposition in downstream reaches. Increased flood erosion downstream if peaks increase.

Table 2. Expected Direct and Indirect River Responses to Human Activities with Respect to Navigability Characteristics			
Human Activity	*****	**Expected Direct Response**	**Expected Indirect Response**
Encroachment (Development, Roads, Railways)		Narrowing of channel or floodplain may increase flow velocity. Increased scour (deepening) near protected channel banks. May increase downstream flood peaks due to storage loss.	May changes natural river processes of meandering, braiding. Increased flood peaks may induce erosion changes in main channel.
Road Crossings (Bridges, Culverts, At-Grade)		Creates obstacles or obstructions to boating.	Changes natural river processes of meandering, braiding. Improves access to river for some types of boating.
Consumptive Use of Water		Decreased flow rates, especially at low flow conditions. Lower flow depths & widths.	Channel geometry may change to reflect new flow regime.
Ground Water Withdrawal		Not a direct impact on boating.	Long-term flow depletion, especially in low flow conditions.
Logging/Removal of Riparian Vegetation, Grazing in the Active Channel		Increased bank erosion, braiding. Increased log jams & strainers – obstacles to boating.	Shallower flow depths in wider, eroded channel.
Ranching, Agriculture		Cross-channel fences may create boating obstruction, or collect debris and block the channel.	Grazing in the active channel can change bank vegetation (increase erosion), alter runoff and sediment supply, and induce braiding in some situations.
Irrigation Return Flows Treated Effluent Discharges		Discharges restore some depleted flow rates or add to ordinary flows. Adds to base flow.	Increase growth of riparian vegetation, creating strainers or blockages.
Urbanization		Not a direct impact on boating, except where urbanization includes floodplain or channel encroachment, channelization or other direct alteration of the active channel (described elsewhere).	Flow depletions from diversions, consumptive use, water storage, ground water withdrawal, flood control. Flow additions from dry weather flows, effluent discharge. Channelization, bank protection, road crossings, loss of wetlands, watershed land use changes.
Land Use Change		Not a direct impact, except land within active channel is developed (described elsewhere).	Depends on type of change. Most frequently, increased flood frequency, flood peaks, and channel erosion (scour & lateral), and decreased sediment supply and low flow rates.
Deforestation in Watershed, Over-Grazing in Watershed		Not a direct impact on boating.	Increased flood peaks in river. Increased sedimentation into river channel, causing lower depths, and increasing riffles, braiding, boating obstacles, and
Loss of Wetlands		Not a direct impact on boating.	Increased flood peaks and channel erosion.
Exotic & Invasive Species		May choke boating channel with vegetation.	Change in bank erosion rates. Alter channel processes of meandering, braiding.

Table 2. Expected Direct and Indirect River Responses to Human Activities with Respect to Navigability Characteristics			
Human Activity	*****	**Expected Direct Response**	**Expected Indirect Response**
Human Induced Climate Change		Direct impacts are unclear at this time, but may include impacts on base flow, flood frequency, watershed cover.	Many indirect impacts are possible due to changes in precipitation and temperature. Ultimately, channel geometry will adjust to the new water and sediment supply as inputs change and geomorphic thresholds are crossed.
Land Subsidence		Not a direct impact on boating.	Changes in channel slope may affect flow depth & velocity.

Notes:

1. Historical, field, and geomorphic analyses are generally required to demonstrate that the expected response actually occurred, when it occurred, and the extent to which it occurred.
2. Not an exhaustive list of possible river responses. Responses listed are the possible responses related to navigability.
3. Red indicates "Probable High Impact."
4. Orange indicates "Probable Moderate Impact."
5. Green indicates "Probable Low Impacts"

A complete discussion of channel responses to human actions is beyond the scope of this report. The following sources are good references for more detailed analysis of that topic:

- Leopold, Wolman & Miller, 1992, Fluvial Processes in Geomorphology
- Schumm, 1977, The Fluvial System
- Simons Li & Associates, 1982, Engineering Analysis of Fluvial Systems
- MacBroom, 1981, Applied Fluvial Geomorphology
- Thorne, Hey & Newson, 1997, Applied Fluvial Geomorphology for River Engineering and Management

Expected Versus Actual River Response to Human Impacts

The mere presence of human activities in a river or its watershed does not necessarily mean that the entire river is no longer in its natural condition with respect to navigability. Rivers are complex multi-variate systems. Therefore, the textbook response to any specific human activity may not have occurred in an impacted river for any of the following reasons:

1. Time. Some indirect impacts require time to fully develop. In some cases, it may be decades or longer before the effect of indirect human actions can be observed and measured in the river channel. Obviously, direct impacts on the river channel are seen immediately within their footprint, but any translation or migration of the direct impact to adjacent stream reaches may take a long time.
2. Scale. In general, the larger the disturbance, the larger (and faster) the consequence. Similarly, a human impact that is small relative to the size of the river or watershed will tend to have only minimal or local impacts on the river.
3. Recovery. Natural river systems can recover from some human impacts, particularly where the impact was a one-time event or small in scale, or where the rest of the river and watershed are untouched. Conversely, some human impacts could cause a river to cross a geomorphic threshold, triggering a response that is more permanent, such as initiation of arroyo formation in over-grazed or urbanized watersheds.
4. Resilience. Natural streams experience a natural range of flows, from droughts to extreme floods, and a fluctuating range of other inputs, such their sediment supply. If the human impacts are within the river's natural range of input variables, there may be no measurable response in the river morphology, or at least to its navigability characteristics.
5. Resistance. Natural rivers may resist change due to the presence of shallow or exposed bedrock, coarse bed material (armoring), clay- or carbonate-rich (caliche) bank or bed material, dense deep-rooted bank vegetation, low flow velocities (and/or depths), or other natural features that stabilize the channel bed and/or banks.
6. Geology. Rivers in bedrock canyons or that are bounded (bed and banks) with resistant materials may not show the expected effects from human impacts that might have caused significant scour or degradation on rivers located in alluvial valleys.
7. Complex Response. Because rivers are complex, multivariate systems, the interplay of specific variables may offset, mitigate, or invert the expected effect of a change in any one variable (Schumm & Parker, 1973).

8. Flood/Flow Series. Rivers need flow to respond to human impacts. If there has been a drought or no significant floods on the river since the onset of the human impact(s), the river may be slow to show the effects from the human actions. Similarly, if the human impact has significantly reduced the river's natural flow rates or eliminated the large, channel shaping floods, e.g. by constructing water storage reservoirs or diversions, the downstream reaches of the river may respond very slowly or not at all to the human impacts.

Therefore, it is necessary to find measurable evidence of the expected river response to human activities rather than just evidence of the activity itself. It is also important to recognize that the presence of human activities does not necessarily equate to degradation of a river's navigability condition. In many cases, human activities increase the boatability of a river, e.g., human management of the Mississippi River is specifically designed to improve navigation.[24]

Summary

Natural rivers are dynamic features, subject to a wide variety of natural processes which create specific characteristics, patterns, and channel types. A river's physical characteristics, like the spectrum of river types, naturally vary over its length in response to changes in runoff rates, sediment supply, geology, climate, vegetation. From the perspective of navigability determination, the most important physical characteristics of a river are its depth and width, as well as the types of obstacles and obstructions found along the river. Human activities can significantly change the natural physical characteristics of a river, though they may or may not substantively impact the river's navigability characteristics.

[24] Note that if the river is navigable solely because of human modifications, i.e., it was not boatable in its ordinary and natural condition, then the river would be considered non-navigable for state title purposes.

Chapter 4:

Ordinary Physical Condition of a River

Lacking a statutory definition for the term "ordinary," the Arizona Court of Appeals in Winkleman v. ANSAC relied on Black's Law Dictionary for their definition:

> *"Occurring in the regular course of events; normal; usual."*

The Court specifically noted that ordinary excludes "drought" or "exceptional conditions in times of temporary high-water," and also held that ordinary means the "conditions prevailing throughout the greater part of the year." The Court's definition focuses more on the ordinary flow rate of a river, rather than on the physical condition of the river channel. But by explicitly excluding "exceptional" floods and droughts, and implicitly including everything else, as long as those conditions are natural, the court implies that the ordinary part of a river corridor excludes the portion of the river that is:

(1) Affected only by exceptional floods, and
(2) Not the river's characteristics and processes found during unusual droughts

That is, the river's physical conditions that exist between flood stage and drought conditions constitute the physical extent of the ordinary condition of the river.

Ordinary High-water Mark

There is a confluence of terminology between the term "ordinary" and the phrase "ordinary high-water mark" that helps define the extent of the ordinary part of a river corridor. The federal definition of "ordinary high-water mark" is:

> *"The line on the banks of a watercourse established by fluctuations of water and indicated by physical characteristics, such as a clear natural line impressed on the bank, shelving, changes in the character of the soil, destruction of terrestrial vegetation or the presence of litter and debris, or by other appropriate means that consider the characteristics of the surrounding areas" (33 CFR 328.3(e)).*

The ordinary high-water mark is a physical, identifiable feature found along a river corridor that demarks the boundary between the land areas regularly shaped and affected by river flows and land areas that are shaped by upland, non-riverine processes (e.g., soil formation, slope processes, etc.). The ordinary high-water mark is used in a variety of boundary determinations such as the jurisdictional limit of "waters of the United States" regulated under the Clean Water Act. The ordinary high-water mark is also used in navigability determinations as the physical boundary of sovereign lands on navigable watercourses.[25] There are numerous published guidance documents that describe procedures for

[25] Some States use the ordinary low water mark in navigability determinations. However, on many rivers there is no readily identifiable physical feature that corresponds with low water. Identification of a low water mark would be problematic during normal flow because it would be submerged. The portion of Arizona's navigability law that limited the State's claim to the ordinary low water mark was removed when the legislation was rewritten after Arizona Court of Appeals 2010 Winkleman v. ANSAC decision.

identifying the ordinary high-water mark on various types of rivers in a wide variety of climatic and geographic settings (Wohl et. al., 2016).

The ordinary high-water mark is inclusive of a river's main channel (which is inclusive of the boating channel), bed, and banks, but excludes the rarely inundated portions of the floodplain (areas reached by exceptional floods). Generally, the ordinary high-water mark includes beaches and bars along the margins of the main channel, and the areas regularly inundated during periods of seasonal high flow.

Therefore, the ordinary high-water mark is recommended as the boundary of the ordinary part of a river corridor for the following reasons:

(1) Boundary Law. Navigability law already dictates that the boundary of sovereign lands on navigable watercourses is located at the ordinary high-water mark.

(2) Standard of Practice. There is established precedent and a standard of practice relating to determination of ordinary high-water marks that is relied on in both the scientific and legal communities.

(3) Nexus of Terminology. The use of the adjective "ordinary" to describe flow conditions in navigability determinations and as the legal boundary of public ownership of navigable rivers is not coincidental, and sets a precedent for distinguishing ordinary and non-ordinary high-water.

(4) Natural, Physical Feature. The ordinary high-water mark is naturally-occurring, physical feature formed by the river itself as a result of flows frequent enough to leave a permanent, recognizable mark on the landscape. The ordinary high-water mark separates the river landform that is dominated by fluvial processes from upland landforms that are not directly shaped by river processes.

Natural Disturbances of Ordinary Conditions

The Arizona Court of Appeals also held that ordinary means the "conditions prevailing throughout the greater part of the year,"[26] recognizing that the ordinary natural condition can be periodically disturbed. That is, some natural conditions, processes, and events are not ordinary, and therefore should be excluded from a navigability determination. The following characteristics help distinguish ordinary conditions and processes from unusual conditions and processes:

- Magnitude. Ordinary processes and events typically are of a size that occurs regularly. Unusual conditions may be identified by their extremely large (or small) magnitude. For example, the spring snowmelt season may have flows that are larger than late summer flows, but unless the snowmelt runoff rate exceeds the level that normally occurs in spring, such rises in flow rate would be considered ordinary for that time of year.
- Frequency. Ordinary processes and events occur regularly, frequently enough to be the norm. One would expect to see, or at least not be surprised by seeing, ordinary river processes in

[26] The "greater part of the year" standard set by the Arizona Court should be interpreted as the "greater part of the [unfrozen part of the] year" in parts of Alaska and portions of other States where rivers may freeze for more than six months. Trade and travel "on" (solid) water in frozen rivers is certainly possible, but has not been considered in past navigability determinations.

action during a field visit (e.g., sediment transport on the stream bed, or elevated flow rates during the snowmelt period), but would be surprised to witness processes that rarely occur (e.g., a landslide into the river channel from a canyon wall).

- Duration. Ordinary river processes often have long durations, and are usually occurring during a significant portion of the year (e.g., annual spring runoff lasts for weeks or months). Most floods that exceed a river's ordinary high water mark have very limited durations. For example, a single summer monsoon flood in Arizona typically last for only a few hours, and thus is not ordinary. Conversely, somewhat elevated flows rates occurring between individual floods during Arizona's summer monsoon season, or high flow during the spring snowmelt period, may last for weeks or months, and therefore would be considered ordinary for that time of year.
- Predictability. Ordinary events and processes occur at expected, regular times of the year and within an expected range of magnitude. Spring runoff, a.k.a., spring flooding, is part of the ordinary condition of the river because it occurs regularly within an expected range of flow. In contrast, individual floods during Arizona's summer monsoon might occur only a handful of times at any time (or not at all) over a period of several months.
- Permanence. Ordinary events do not significantly alter the normal condition of the river, lending the river condition some sense of permanence and continuity. Unusual events may substantively alter the river condition. After an unusual event that disrupts the ordinary condition, a natural river will usually begin to reestablish the pre-event ordinary condition.

Examples of non-ordinary, natural processes that impact the ordinary river conditions include the following:

- Floods. By definition, floods are not part of the ordinary condition of the river, although floods are certainly natural events.[27] Extreme floods can significantly alter the ordinary portion of the river by removing bank vegetation, widening and/or deepening the main channel, depositing or eroding bed and bank sediments, creating (or removing) log jams, or changing the location of the main channel within the floodplain. That is, while the flood is not ordinary, it can alter the condition of the river compared to its pre-flood characteristics. Whether the post-flood changes can be considered part of the ordinary condition of the river is a function of the frequency of such flooding, the persistence of the altered conditions in the river landscape (i.e., the recovery rate), and the duration of flood-altered conditions relative to the river's long-term condition. In drylands, where extreme floods (e.g., a 100-year flood) tend to be significantly larger than base flow as well as ordinary, annual floods (e.g., a 2-year flood), the effects of extreme flooding can persist in the floodplain for long periods of time. However, within the main or boating channel, rivers tend to return to a more ordinary condition relatively quickly. And it is the condition of the boating channel that it is of most importance to a navigability determination. Therefore, where extreme floods have altered the river corridor, the technical evaluation should focus on any impacts to the main channel, rather than on impacts to the floodplain.

- Tributary Floods. Major floods on tributaries can leave large deposits of sediment at the confluence with the main stem channel (Figure 27). The sediment may form new, or alter existing, rapids in ways that affect boating. Such deposition is more common, and more likely to

[27] See Chapters 6 and 7 for further discussion regarding the definition of floods.

affect boating, in canyon rivers than on flatland rivers. The duration of such changes to the main stem river is a function of the magnitude of the tributary flooding, the type of sediment deposited by the tributary relative to the main stem river's capacity to transport sediment, and the time until high flows or a large flood occurs on the main stem that is able remove or rework the tributary deposits. For example, in Grand Canyon, the December 1966 flood on Crystal Canyon rendered Crystal Rapid very difficult to boat for several decades.[28] In contrast, a large flood on Granite Spring Canyon created a new, larger rapid at mile 220.7 of Grand Canyon during the summer of 2016, but by December 2016 the rapid had already returned to the pre-flood condition.

- Wild Fire. Although many modern wild fires are human caused, wild fires occur naturally as well and are an important part of the natural ecology of watersheds. Post-wild fire conditions are conducive to extreme flooding, excessive sediment erosion, formation of debris flows, and delivery of downed trees to river corridors, all of which may temporarily alter the boating condition of a river. Such changes are generally short-lived, with a return to pre-fire hydrologic conditions in less than a decade in many cases (Ryan and Dwire, 2012). Impacts of wild fires on a river corridor may or may not occur, and are likely to be similarly short-lived and of limited extent.

- Debris Flows. Debris flows are slurries of water and sediment which occur on very steep slopes and can be conveyed along some steep channels and narrow canyons. Streams that convey debris flows are typically too steep for most types of boating. However, debris flows conveyed down steep tributaries may debouch into a main stem river channel that supports boating. Such debris flow deposits may create very temporary obstructions if they are large enough to block and dam the main channel. More commonly, debris flow deposits on the main stem channel create rapids or riffles of varying complexity, persistence, and difficulty, and are likely to be localized, short-term perturbations in the ordinary condition of the river.

- Log Jams. Log jams may form naturally in some rivers, and may create obstacles or obstructions to boating depending on their unique characteristics and the type of boat considered. Some log jams may remain in place for long periods of time, depending on the size of the log jam and flood cycle of the river, and may become the ordinary condition at that point in the river for as long as they remain in place. Some river reaches are prone to log jams due to their morphology and watershed characteristics. In such cases, it would be necessary to find ways to determine the age of the log jam, whether it existed at statehood, the degree to which it was natural or human-caused, whether it was a temporary or permanent feature, and to what degree it affected boating on the river.

- Beaver Dams. Beaver dams are natural features that may adversely impact some types of boating. Determining if beaver dams were part of the ordinary condition of the river would

[28] Note that the natural flood response of the Colorado River at Crystal Rapid was substantively altered by the construction of Glen Canyon Dam (Lake Powell) in 1963, slowing the river's ability to re-shape the rapid to the pre-flood condition. Since the 1983 flood in Grand Canyon, Crystal Rapid is more routinely boated, though it remains one of the largest rapids in the canyon.

require knowledge of whether beaver dams existed at statehood or whenever the river was in a natural condition at that time, and if not, to what degree human trapping of beavers may have affected the number and extent of dams on each river segment. Most importantly, it would require knowing something about the frequency (spacing) and permenance of dams on each river segment. Note that the presence of beaver dams on one river segment does not mean beavers would have dams, or the same kinds of dams, on all segments of the river. It would also require knowing the character of the dams, such as whether the dams spanned the boating channel or were located on side channels, or whether the dams included boatable sluices. The assessment would also need to examine to what degree beaver dams made the river more boatable by raising water levels or metering downstream low flows versus creating localized obstacles to boat passage.

- Bank Failures/Erosion. Bank erosion is a naturally occurring process on nearly all alluvial rivers. Bank erosion can cause bank failures where, in some cases, the bank sediments collapse into a boating channel, potentially creating a boating obstacle. Whether a particular bank failure was ordinary or unusual would require consideration of the extent, frequency, magnitude, and impact on boating of the bank failures commonly observed on the river, as well as how long the bank failure continued to impact boating before the sediment from the bank collapse was transported away by the river. It would also be important to determine if the observed bank failures represented a condition likely to have existed at the time of Statehood. Most likely, in an otherwise natural river and watershed, while the exact location of bank failures at Statehood could not be predicted with certainty, the general rate and type of occurrence probably would be similar to the observed conditions.

- Tree Fall. As river banks erode natural, it is not unusual for bank vegetation to fall into the river channel, creating strainers or sweepers which can be obstacles for boating in some circumstances. Whether a particular tree fall was ordinary or unusual would require consideration of the extent, frequency, magnitude, and impact on boating of the tree falls commonly observed on the river, as well as how long the tree fall continued to impact boating before being removed by the river. It would also be important to determine if the observed tree falls represented a condition likely to have existed at the time of Statehood. Most likely, in an otherwise natural river and watershed, while the exact location of tree falls at Statehood could not be predicted with certainty, their type and frequency of occurrence probably would be similar to the observed conditions.

- Arroyo Formation. Channel incision events are inherently non-ordinary events that would significantly and permanently alter the ordinary condition of a river. Arroyo formation would be somewhat unlikely to occur on a navigable river, but a navigability determination on a river that had experienced an incision event would need to consider the timing of the incision relative to the time of Statehood, the relative impact of human and natural causes, and whether the change resulted in a more or less boatable stream channel.

- Slope Failures. Slope failures from the wall of bedrock canyons into a river could impact boating conditions by creating a new rapid or narrowing (or blocking) the boating channel. Whether a particular slope failure was ordinary or unusual would require consideration of the extent, frequency, magnitude, and impact on boating of the other slope failures observed on the river, as well as how long the slope failure continued to impact boating before being removed by the river. In general, slope failures are relatively rare occurrences[29] and would be unlikely to be considered an ordinary condition process. Similarly, they would be unlikely to impact a significant length of a river segment, and often do not affect the boating conditions on the river. It would also be important to determine if the observed slope failure represented a condition likely to have existed at the time of Statehood. Most likely, in an otherwise natural river and watershed, while the exact location of slope failures present at Statehood could not be predicted with certainty, their general occurrence probably would be similar to the observed conditions.

- Avulsions. Channel avulsions are inherently non-ordinary events that result in a permanent relocation of the channel within the floodplain. In boundary law, public ownership does not follow the boundaries of an avulsive channel change once a river is found to be navigable. Therefore, it is important to establish the timing and progress of the avulsion relative to Statehood, the location of the pre-avulsion channel and ordinary high-water mark (if the avulsion occurred after Statehood), and any changes in slope or channel geometry in the adjacent stream reaches caused by the avulsion.

- Stream Piracy. Natural headward erosion of stream channels or erosive overbank flooding can result in stream piracy, or stream capture, where the captured stream is diverted into the channel of the eroding stream, resulting in a permanent change of channel position and characteristics. On most rivers large enough to be susceptible to navigation, stream piracy is extremely rare, and would be considered an avulsive channel change, as described above.

- Climate Change. Some climate change occurs naturally, but typically occurs over long time scales at rates that would make identification of channel responses relative to specific date of Statehood difficult. Furthermore, it would be difficult to distinguish natural and human-caused climate change channel impacts. In general, the slow rate of climate change would make it ordinary, although the cumulative effects of a century or more of climate change might cause a significant departure from the ordinary conditions that existed at the time of statehood.

For any of the natural interruptions of a river's ordinary physical condition, if the interruption did not result in a substantive change to the boating condition of the river, it is not necessary to evaluate it in greater detail. Human disturbances of natural, ordinary conditions were discussed in Chapter 3.

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[29] Slope failures, such as rock fall, may be more common in cold climates where freeze-thaw processes occur than in warm, arid climates. Even so, rock fall would not be considered "ordinary" over the length of an entire river segment, as that term is defined in this report, e.g., one would not expect to see a new rock fall or slope failure on most days. However, on many canyon rivers, it is not uncommon to see the effects of rock falls, as boulders may persist in the channel for a very long time.

Summary

Natural streams are not static. Some level of channel change is ordinary, and is a function of the type of river. What is ordinary for a braided glacial outwash stream may be extraordinary for a meandering flatland river. What constitutes the ordinary physical condition of a river can be better understood by examining both the long-term history of river conditions, and the types of conditions observed on adjacent river segments and similar river types.

Chapter 5:

Determining the Ordinary & Natural Physical River Conditions: Recommended Methodology

The recommended methodology for identifying and describing the ordinary and natural physical condition of a river is presented in this Chapter. The methodology focuses on the "ordinary" portion of a river, as defined in Chapter 4, but also considers the potential for human impacts occurring outside the ordinary part of a river corridor to have substantive indirect impacts on footprint of sovereign land along a navigable river. The methodology presented in this Chapter applies primarily to the physical condition of the river. Procedures for determining a river's ordinary and natural flow rates are described in Chapters 6, 7, and 8.

Overview

Determining if a river is in its ordinary and natural condition with respect to navigability begins with an assessment of the existing condition of the river, its floodplain, and its watershed. If the river is currently in a natural condition, substantively undisturbed by human activity, then the required investigation is limited only to determining if there were historical human disturbances from which the river has already recovered, and documenting the natural physical conditions of the river, as described in Chapter 3 of this report. The natural physical conditions that should be catalogued and described include river depths, widths, channel pattern, obstacles, obstructions, and ordinary high-water marks.

If the river is no longer in its ordinary and natural condition, or if was previously disturbed and has since recovered a natural condition, then the methodology is more complicated and labor-intensive. Even if the river has recovered its natural navigability characteristics after past disturbance(s), it is valuable to document the nature of the disturbance so that the historical record of river use (or non-use) can be interpreted in its correct context.[30] If the river's natural condition has been altered, then the analysis should focus on documenting the type, extent, timing, and locations of human impacts that have occurred, as well as on how the impacts affected the river's navigability characteristics, such as flow depth, channel width, channel pattern, obstacles, obstructions, and ordinary high-water marks. The analyses should be particularly cognizant of the timing of human impacts with respect to the date of Statehood and the dates of significant historical river uses (or non-use), such as boating or floating logs. Finally, the analysis should establish the time period in which the river was last in its natural condition, which should be the primary focus of the navigability investigation.

[30] See the Mosquito Fork Case History in Chapter 9 for an example of a river that was disturbed to some degree by pre-statehood mining, but has since recovered its natural navigability characteristics.

The recommended procedure for determining a river's ordinary and natural physical condition consists of the following elements:

- Step 1: Initial Reconnaissance
- Step 2: Historical Analysis
- Step 3: Field Investigation
- Step 4: Evaluation of Human Impacts of Navigability Characteristics

The ordinary and natural condition investigation is typically performed in conjunction with other standard elements of a navigability assessment that may be led by other subject matter experts on the project team. Other disciplines represented in a navigability study may include regional and river-specific historical analysis (historian), hydrologic analysis (hydrologist), geomorphic assessment (geomorphologist), and a boating analysis (historical and modern boat experts). Also, because navigability work is a legal process, attorneys are essential part of the team. Integration of the findings from all disciplines is valuable, and can be an iterative process of discovery and evaluation.

Step 1: Initial Reconnaissance

The initial reconnaissance tasks consist of looking at the entire river and watershed. If the river looks natural, it is most likely that the river is still in its ordinary and natural condition. However, there are exceptions that merit consideration. For example, ground water withdrawal from wells may have significantly depleted the natural flow, and the river may have already adjusted to the new flow regime, making the changes difficult to detect without more detailed study. In other cases, such as the Merced River in Yosemite National Park, where the natural river morphology has been altered by removal of glacial moraines to accommodate roads and drain spring swamps, albeit beautifully, a casual reconnaissance might not detect the man-made alterations to the natural channel morphology.

On the other hand, if the river is dammed and diverted, and if the watershed is crisscrossed by roads, pockmarked with cities and mines, and blanketed by farmlands that replaced native forests, the river probably (but not necessarily) has changed from its pre-development navigability condition.

An initial reconnaissance-level existing condition assessment of the river and its watershed can be performed using readily-available digital topographic maps and aerial photography, such as Google Earth imagery and free online Geographic Information System (GIS) mapping and other data.[31] Recent maps and aerial photography should be carefully examined to identify the types of human impacts listed in Table 2. Note that some of the small-scale human activities like small diversions or direct pumping from the river may be difficult to identify on large-scale aerial photographs, and may not be shown on most types of readily available topographic maps. Field investigation may be required to identify the

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[31] Digital USGS topographic maps for the entire United States are available free through a variety of online repositories. Many state and federal agencies, academic institutions, and libraries also have a wide variety of free GIS land use, land ownership, vegetative cover, aerial coverage (historical & modern), stream information, geological, and other geographic data sets that are useful for navigability determinations. Because the types of data, repositories, web addresses, and platforms change periodically, they are not listed is this report.

less obvious forms of human activities. Any human impacts that can be identified from maps and aerial photography should be catalogued, mapped, and described. In addition, the existing physical characteristics of the river, the floodplain, and the watershed should be fully described relative to the natural and non-natural features discussed in Chapters 3 and 4.

A literature search may also be a useful element of an initial reconnaissance to identify published research or other studies describing changes in river or watershed conditions, either for the river in question or for the general region near the river, e.g., studies of channel impacts from historical over-grazing of watersheds in the arid west, or studies of climate-change induced glacier retreat on stream morphology. Other relevant types of published research or grey literature might include fish or riparian habitat studies, water supply papers, reports on invasive species, geomorphic studies of channel change, impact or feasibility studies associated with new or existing dams or diversions, floodplain delineation studies, or navigability studies on nearby rivers. Such studies may explicitly or implicitly detail the history of human-caused changes in channel conditions, significantly reducing the required level of effort for the ordinary and natural condition evaluation.

The outcome of the Initial Reconnaissance will include the following:

(1) Preliminary assessment of whether the river is likely to be in its natural condition.
(2) A list of human activities that have left visible evidence in the river corridor and watershed.
(3) A catalog of the locations, extents and types of human-caused disturbances of the river corridor and watershed.
(4) A bibliography of past research and reports describing river and watershed changes.
(5) A list of aerial photography and map sources, dates, and scales for the study area.
(6) A list of sites and reaches targeted for closer examination during the Field Investigation.

The information collected in the Initial Reconnaissance should be shared with the rest of the project team to facilitate its dissemination and to get feedback from the other subject matter experts and legal counsel, and especially from the team members performing the historical analyses.

Step 2: Historical Analysis

With respect to determining the ordinary and natural condition of a river, historical analyses should be performed to identify past uses of the river and its watershed, including all the activities listed in **Table 2**. Most parts of the historical analyses are typically done by an historian, but other portions such as interpretation of historical maps and aerial photographs may be performed by a qualified geomorphologist, hydrologist, civil engineer, or surveyor, and tasks relating to historical or modern boating may be performed by a boating expert. The expert working on the ordinary and natural condition assessment will use information collected by the rest of the team.

If possible, the following historical information should be obtained for each type of identified disturbance:

- Dates. For each type of human impact, the start date, the end date, the time of peak use, and any time gaps when the activity ceased should be identified.
- Scale. The extent and magnitude of the human activity should be quantified, e.g. acreage of irrigated agriculture, tons of material mined, size and capacity of structures (dams, canals, etc.), extent and frequency of river dredging, etc.
- Location. The sites where human activity occurred should be mapped relative to the river channel and watershed boundaries.

In many cases, the types of information and the level of detail noted above may be difficult or impossible to obtain. In such cases, the relative magnitude of human activities can be approximated by analyzing and comparing modern and historical maps and aerial photographs, or by considering other types of historical descriptions and narratives collected as part of a navigability assessment. Relevant historical descriptions can be obtained from General Land Office (GLO) boundary survey notes, pioneer diaries, logs and diaries of early explorers, historical newspaper accounts and photographs, museum or university archives (maps and photographs), local historical societies, and other sources that describe historical activities along the river corridor and in its watershed, as well as accounts of boating on the river.

Quantified historical information is especially useful when combined with analysis of historical maps and aerial photographs which depict changing (or unchanged) river conditions, so that a chronology of historical and modern impacts and changes can be established. If historical flow data about dates of large floods and periods of drought are also available (Chapter 8), it may be possible to distinguish natural flood responses and processes from channel changes likely to have been caused by human activities by comparing the timing of human activities to records of river flows.

Quantified historical information can also be obtained by comparing historical aerial photographs from different time periods. Of course, except for Alaska, Hawaii, and any future states, the date of statehood preceded the advent of aerial photography, so care must be taken in mistaking the earliest available aerial photography for representing the natural condition of the river. For example, even though Arizona was the most recent of the lower 48 states to join the Union, by the time the first aerial photographs were taken in 1930, the lower Salt River had already been so altered that it bore no resemblance to the river described by the early explorers and settlers. The lower Salt River was altered significantly more after the first aerials were obtained and before the first navigability studies were done in the early 1990's (compare Figure 29 to Figure 30), but that did not make the 1930 aerials any more representative of the river's undisturbed natural condition. Nonetheless, for assessing the impacts of human activities that occurred in more recent time periods, comparing channel conditions visible on sequential aerial photography is highly effective.

It is also useful to collect records of historical boating, particularly the types of boats used, the reaches boated, and the times of the year boating occurred. Knowing what types of boats were used provides clues to the historical river conditions. In addition, any descriptions of the river (depths, rapids, obstacles, landmarks, etc.) or the boating experience itself (challenges, mishaps, level of difficulty (or ease) of boating, etc.) are particularly useful for identifying changes between historical and modern conditions. The absence of descriptions of obstacles or difficulties in historical accounts may also be useful for reconstruction historical ordinary conditions.

Figure 29. 1937 aerial photograph of the Salt River in Phoenix, showing same extent as Figure 30.

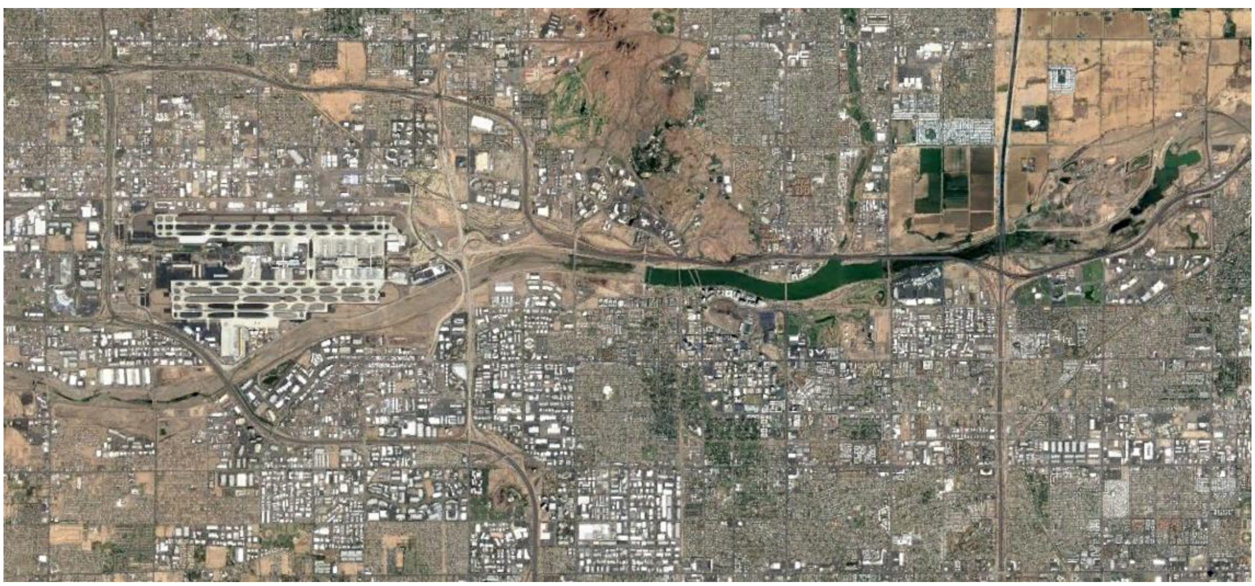

Figure 30. Aerial photograph of the modern Salt River channel in Phoenix, Arizona. The only non-flood surface water in the modern Salt River is from Tempe Town Lake, an artificial lake formed by retractable dams and external water sources, and dry weather flows from the Tempe drain channel and Price Freeway drain.

The degree of channel change due to human impacts may also be evaluated by comparing some types of historical maps and aerial photographs. In particular, changes in channel pattern and channel width can be readily compared, as shown in Figure 32. However, there are several points of caution that should be used when making such comparisons, including the following:

- Accuracy. Historical (and modern) maps are made with varying levels of levels of precision and skill. It is important to not overestimate the accuracy of any individual map when making numerical measurements on two different maps.
- Purpose. Maps are made for specific purposes, and the effort that goes into portraying specific features, such as a river channel, mountain or road, may vary depending on the purpose, which may have consequences for the accuracy of the map's depiction of the feature. For example, historical road maps may show the approximate location of a nearby river, but are unlikely to provide any reliable information about channel widths or the exact location of the channel boundaries (Figure 31).
- Flow Rate. When making measurements of map features such as river width, which may vary seasonally, it is important to try to determine the conditions under which the feature was mapped or photographed.

Figure 31. 1899 map of Arizona near Phoenix. The map pre-dates statehood, but provides little useful detail for an ordinary and natural condition assessment.

Some navigability characteristics, such as river depth, are usually difficult to quantify from most historical maps and aerial photographs, although some useful inferences can be made in some cases, by making comparisons of stage, extent of inundation, or submergence of prominent features that have persisted in the landscape over time. In other cases, historical descriptions can be useful for making broad estimates of river conditions. For example, a historical account may include a description of a difficult river crossing from which the river depth (deep enough to float a boat versus ford or wade, deep enough to drown, or to flip a boat), velocity (fast moving water), width (long crossing), or other conditions can be inferred. Alternatively, the presence of mapped features or place names on old maps may provide clues to historical river conditions, e.g., ford or ferry crossings marked on the map, or place names such as Hayden's Ferry, Old Tom's Ford, or a town called Beaver Dam.

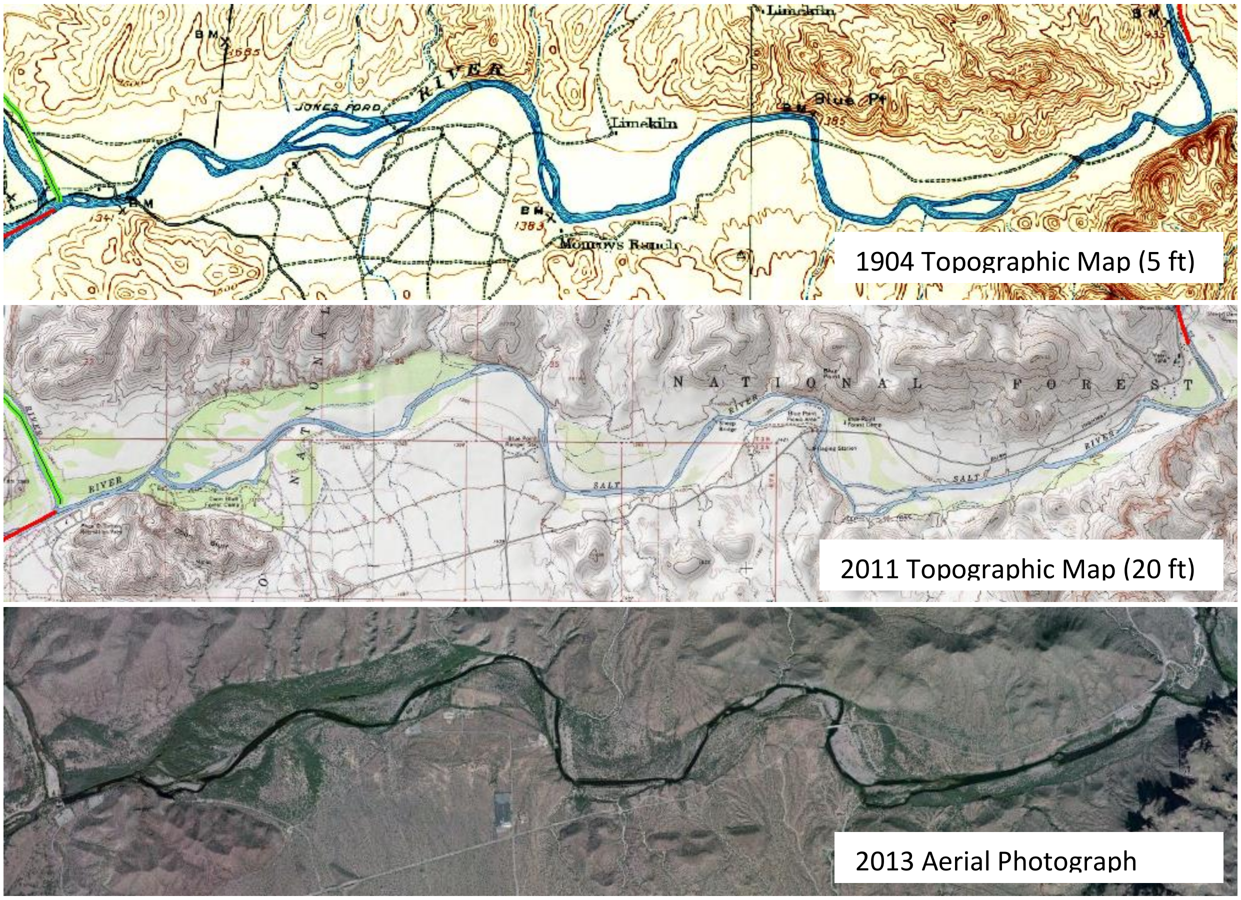

Figure 32. Comparison of historical and recent topographic maps and aerials for a portion of the Salt River, Arizona indicating minimal change in channel pattern, widths, and channel position from 1904 to 2011 despite major human impacts upstream.

The outcome of the Historical Analysis will include the following:

(1) A supplemented list of human activities that have left visible evidence in the river corridor and watershed.
(2) An expanded and quantified catalog of the locations, extents and types of human-caused disturbances of the river corridor and watershed.
(3) Maps showing change or permanence of river channel patterns, widths, or channel positions.
(4) A list of historical aerial photography, map, photographs and other reference materials for the study area.
(5) Historical descriptions of river characteristics at specific locations that can be checked during the Field Investigation.
(6) General historical descriptions of river depth, width, obstacles and river conditions that can be compared qualitatively to existing field conditions along the river.

The information collected in the Historical Analysis should be shared with the rest of the project team to facilitate its dissemination and to get feedback from the other subject matter experts, especially from the team members performing the Field Investigation.

Step 3: Field Investigation

In many cases, a reasonably reliable estimate of whether the river is likely to be in its natural condition can be made based solely on the Initial Reconnaissance and Historical Analyses, particularly if the watershed appears to have been largely undisturbed by human activity. However, a thorough field investigation significantly improves the reliability of assessment, even where the watershed and river corridor are largely undisturbed. Alternatively, if there have been significant human activities in the along the river or in the watershed, then it is critical that the ordinary and natural condition assessment include a thorough field investigation of the river corridor. It is only by performing field studies and by observing actual river conditions that it can be known whether human activities have altered the navigability characteristics of the river. For example, it is not sufficient to identify the presence of a dam during the Initial Reconnaissance and hypothesize that the river's physical characteristics substantively changed downstream of the dam because that is the expected response to a dam. It is necessary to first determine if the expected response has occurred, and then to quantify the timing, magnitude and extent of the response so that it can be determined if and when any actual change impacted the boatability of the river.

While it may be helpful to view the river corridor from a low-level helicopter or airplane flight, or on the ground at whatever road crossings exist along the river as an initial step in the Field Investigation, it is far more useful to perform *navigability* field work *by boat*. If field work is done from a boat, the entire length of the river can be observed at close range and at a pace that facilitates careful consideration and reach-to-reach documentation of river conditions. Observing the river from a boat also allows better access and sight to both banks of the river, as well as to the characteristics of the boating channel itself, as compared to doing field work on land from one side of the river. Because the ability to boat the river is directly relevant to determining its navigability, boat-based field work has its own merit, in addition to evaluating the impact first hand of any human activity on boating conditions in the river.

If the river can no longer be boated due to human impacts or other changes, then the Field Investigation should be performed along a traverse within the ordinary high-water marks along the river's entire length, either on foot or by all-terrain vehicle (ATV) travel. However, if the river has been so altered by human activity that it bears no semblance to its natural condition, then the value of detailed field investigation in a boat or on foot is greatly diminished, at least for the purpose of determining the ordinary and natural condition. This was the case for the completely diverted, dried up, channelized, mined, and encroached lower Salt River in Phoenix (Figure 30). It such cases, one must rely more on historical records and inferences from less disturbed portions of the river than on modern field observations of the disturbed reaches.

The Field Investigation should include the following elements:

1. Description of Existing River Characteristics. Documentation of existing river characteristics such as the channel pattern, typical flow depths, channel widths (and variability), the types of boating obstacles and obstructions, and other features is useful to provide a basis of comparison to

historical descriptions of the river. The descriptions are also useful for defining river segments, and as a means of distinguishing any differences in river characteristics near known locations of human activities along the river corridor. Evidence of any of the river characteristics listed in the checklist provided in Table 3 should be thoroughly described. Field descriptions and measurements of river depth, width, obstacles and other physical characteristic should then be compared with historical measurements and descriptions to determine the direction, magnitude, and nature of any changes.

2. Description of Existing River Processes. Documentation of existing river processes such as meandering, braiding, bank erosion, avulsions, scour and deposition, or flooding is useful to provide a basis of comparison to historical descriptions of the river, and to distinguish between processes that are expected for the given river type, and those that are unusual and might be indicative of human impacts on the system. Evidence of any of the river processes listed in the checklist provided in Table 3 should be thoroughly described. Descriptions of river processes observed in the field should then be compared with historical measurements and descriptions to determine the direction, magnitude, and nature of any changes.
3. Identification of Geomorphic Indicators of Channel Disturbance. Rivers that have been impacted by human-induced changes often display specific characteristics that can be identified in the field. The occurrence and type of those indicators should be mapped and quantified. A listing of some of the more common field indicators of channel change and instability are shown in Table 4.
4. Identification of Disturbed and Natural Stream Reaches. A river may be impacted to differing degrees over its lengths. Some reaches may be unchanged and still in their natural condition, even where human impacts have been significant. Unchanged, still natural reaches are most likely to be found in the most remote parts of the watershed and upstream of any direct human impacts on the river corridor. Even direct impacts on the river channel are likely to affect only the portion of the river closest to the point of impact. Other reaches may be partially altered, and others may be completely transformed due to human impacts.
5. Quantification of Channel Characteristics in Disturbed and Natural Reaches. Careful description of key river characteristics, such as depth, width, channel pattern, obstacles, bed and bank materials, bank vegetation, riffle spacing, floodplain elevation(s), etc., can help identify subtle changes that may be related to nearby human impacts. It is important to describe both changed and unchanged reaches so that the differences can be identified, and the departure from the natural condition can be quantified. Of particular importance are the types of channel changes that most directly impact boating, such as changes in flow depth or the development of new or more severe obstructions. The river characterization should reflect the channel pattern and processes expected for that type of river.
6. Detailed Descriptions of Channel Characteristics at Known Historical Disturbance Sites. For each location of known human activity in the river corridor, particular attention should be paid to the channel and boatability characteristics at the site and in the adjacent stream reaches. Differences in channel depth, width, obstacles, rapids, riffles, bank conditions, bed materials, etc. in the historically disturbed area should be noted relative to upstream and downstream reaches outside the footprint of historic disturbance. A checklist of common human activities

that impact rivers is provided in Table 5. When using the checklist, it may be helpful to compare the expected channel responses (Table 2) to those actually observed in the field. If any substantive differences between the channel reaches near human impacts and natural reaches are detected, then additional historical research, including review of historical maps, aerial photographs, and flow records is recommended to identify the timing of when such changes may have first appeared relative to the time of statehood or any historical accounts of boating.

The outcome of the Field Investigation will include the following:

(1) A detailed description of river characteristics, summarized by river segment, reach, and location relative to disturbed and undisturbed portions of the study area.
(2) A detailed description of river process, summarized by river segment, reach, and location relative to disturbed and undisturbed portions of the study area.
(3) Field documentation including photographs, boating logs, and written descriptions of key river features.
(4) A list of any indicators of channel instability observed in the field as well as their locations and characteristics.

The information collected in the Field Investigation should be shared with the rest of the project team to facilitate its dissemination and to get feedback from the other subject matter experts.

Table 3. Field Investigation Checklist – River Navigability Characteristics		
Obstacles/Obstructions		
	Type	**Frequency/Severity**
Bars		
Rocks		
Bends		
Strainers/Sweepers		
Islands		
Rapids		
Riffles		
Dry River Bed		
Shallow Water		
Waterfalls		
Beaver Dams		
River Patterns		
Meandering		
Sinuous		
Straight		
Braided		
Spilt Channels		
Compound		
Bedrock Canyon		
Incised		
Avulsive Channels		
Alluvial Fan		
Delta		
River Processes		
Meandering		
Braiding		
Bank Erosion		
Scour		
Sediment Deposition		
Tributary Deposition		
Avulsions		
Floods		

Table 4. Common Field Indicators of Channel Instability from Human Impacts	
Indicator	**Description**
Extensive Bank Erosion	Bank erosion occurs naturally on most rivers, and on some channel types (braided) more than others (meandering). If banks are more eroded than not, or erosion is occurring in atypical places (e.g., inside meander bends, or on both banks), then the erosion may be a sign of human-caused instability. Evidence of recent bank erosion includes fallen or leaning bank vegetation, roots exposed in cut banks, and vertical or undercut banks.
Lack of Bank Vegetation	Most rivers have some level of increased or more dense vegetation along the primary channel banks. If the banks are devoid of vegetation, it may indicate adverse human impacts to channel stability.
Hanging Tributaries	A hanging tributary forms when the main channel incises rapidly, leaving its tributary confluences perched above the new channel bed elevation. Channel incision can be caused by a variety of human-alterations of a river or watershed.
Perched Channels	A perched channel forms when the main channel incises leaving a former channel braid or channel split perched above the new channel bed elevation. Channel incision can be caused by a variety of human-alterations of a river or watershed.
Headcuts	A headcut is a (near) vertical break in the channel slope that can be caused by human disturbance of the channel (e.g., in-stream mining) or human-caused changes in water and/or sediment supply (e.g., deforestation or urbanization).
Irregular Channel Geometry	Some variation in channel geometry is natural and expected. Radical changes in channel depth or width are often the result of human interference.
Change of Channel Pattern	An abrupt change of channel pattern, such as from a meandering single channel to a highly braided channel, particularly where the original pattern reappears in the downstream river reach, is often a sign of human impacts on the channel, though such change also can be indicative of a natural change in the underlying geology, valley slope, or hydrology.
Gullying	Gullying in a watershed can be caused by overgrazing, deforestation, or urbanization, and can cause excessive sediment deposition in the main stem river as well as changes in runoff rates.
Bed Armoring	Stream beds become “armored” with a layer of coarse, immovable sediment (e.g., cobbles) as a result of depletion of the upstream sediment supply and long-term scour, as might occur downstream of a major dam.
Braiding	The occurrence of a reach of highly braided channels in an otherwise single-channel stream system can indicate delivery of excess sediment to the main channel in response to extensive in-stream mining on a tributary, deforestation, removal of bank vegetation by overgrazing, or other human impacts.
Constructed Channel Stabilization Measures	Where rivers have become unstable due to human impacts, adjacent landowners or public agencies often construct stabilization measures like rip rap or concrete bank protection, grade control structures, levees, etc.
Reservoir Sedimentation	River bed sediments found along the channel margins that grade downstream to thick planar deposits of fine sediment may be remnants of deltaic deposition in a depleted reservoir. As reservoir levels recede, the river may cut through the former delta leaving vertical cut banks along the channel.
Large-Scale Vegetative Changes	A drastic change in vegetative cover along the stream banks and on the floodplain that cannot be explained by changes in aspect, elevation, or soil substrate/geology may indicate the presence of invasive species, which may in turn indicate a change in the natural flood and flow regime.

Table 5. Checklist of Human Activities			
Activity	**Description/ Documentation**	**Expected Channel Impact**	**Actual Channel Impact**
Dams			
Reservoirs			
Diversions			
In-Stream Mining			
Channelization			
Levees			
Road Crossings			
Bank Stabilization			
Encroachment			
Navigation Structures			
Dredging			
Logging/Clearing			
Grazing in Channel			
Grazing in Watershed			
Urbanization			
Land Use Change			
Climate Change			
Loss of Wetlands			
Ground Water Withdrawal			
Land Subsidence			
Consumptive Water Use			
Irrigation Return Flows			
Effluent Discharge			
Flow Regulation			
Exotic & Invasive Species			

Step 4: Evaluation of Human Impacts

After completion of the Field Investigation and any additional historical research needed to tie down the timing of known channel changes, all that remains is to quantify the impact of channel changes on the boatability of the river. This can be done by synthesizing the historical and modern river descriptions, historical and modern boating accounts, expected and actual river responses to known human activities, and identifying the discrepancies and commonalities. The evaluation and synthesis should focus on the following key elements:

- Flow Depth
- Flow Width
- Obstacles and Obstructions

Note that in most cases human activities will impact a river's flow rates more than its physical navigability characteristics, particularly if the human activities did not occur within the ordinary high-water marks of the river and even more so if the river has remained perennial. Also, in many cases, there will not be sufficient data from which to precisely quantify the changes. In such cases, the following approaches are recommended:

- Estimate the Direction of Change. In most cases, the direction of change can be observed or estimated from field and historical evidence. For example, if the record indicates that the river incised as a result of upstream human activities, then is likely that newly formed terraces could be identified on aerial photographs or in the field along the river corridor, and that some of the channel instability factors listed in Table 4 would have been observed in the field.
- Estimate the Relative Magnitude of Change. The scale and significance of human impacts can be assessed to determine the likely channel response. For example, if a single in-stream placer mining claim occurred on the river and was only worked for a few seasons, the expected response would be limited, would be unlikely to impact much of the river's length, and would be more likely to recover in a shorter amount of time than if the entire river segment was lined with long-term mining operations. Small changes in flow depth or width, or small increases in the number of types of obstacles, are unlikely to impact the types of boats that can or could have been used on the river. If the depth of the boating channel changed from 2.1 feet to 2.6 feet, or vice-versa, that is unlikely to change what types of boats could have been used on the river, making such differences nearly irrelevant to the navigability determination.
- Focus on the Impact to Boating. Even if the exact characteristics of the human impact cannot be quantified, it may be possible to determine whether or how the activity would have affected boating. For example, assume that over-grazing of the channel corridor was found to have resulted in loss of bank-stabilizing vegetation and increased braiding of a formerly meandering river. This change would have led to increased channel widths and decreased average depths. Therefore, it would be probable that the river would have become shallower and more difficult to boat than it was in its natural condition. As a consequence, records of modern boating would be more likely to be relevant to historical conditions since the river would have been more boatable in the past.
- Evaluate Ordinary Flow Conditions. Human impacts that would only affect flood conditions are less relevant to a navigability determination than direct impacts on the boating channel. Therefore, the evaluation should focus on the portion of the river corridor located between the ordinary high-water marks.

Summary

It many cases it will be neither necessary or possible to perform all the analyses described in this Chapter. The objective of the recommended procedure is to determine if the river is in its natural physical condition, not to perform a specific set of studies. To that end, only the analyses needed to meet the overall objective for the river in question should be performed. If the end goal can be achieved more efficiently, then there is no need to do more.

Chapter 6:

Natural Flow Rate of a River

On many rivers, the natural, pre-development flow rates have been significantly altered by human activities in river and watersheds. Altered flow rates change a river's navigability characteristics. The Daniel Ball test requires that a navigability determination be based solely on a river's natural condition. This Chapter discusses the navigability aspects of a river's natural flow rate.

Natural Flow Variability

The flow rate in a natural river is not constant, but instead varies in response to climate, weather, and other natural phenomena. The following types of natural flow variability are relevant to navigability determinations:

- Episodic. River flows increase due to precipitation and decline between storms. Similarly, a temperature increase in a frozen watershed may result in a pulse of increased runoff. The amount of increased flow is a function of the precipitation (or temperature) magnitude, intensity, and duration, as well as the extent of coverage of the watershed by the weather system(s) or any antecedent moisture conditions. Most episodic flow increases do not reach flood stage and are within the ordinary range of river flow variability.
- Seasonal. On most rivers, there are regular seasons with higher and lower flow rates. Natural seasonal high flow can be caused by a rainy season (winter storms, summer monsoons) or spring snowmelt. Similarly, seasonal low flows may occur in summer when temperatures and evapotranspiration rates are high, at any time of year when precipitation is normally rare, or in winter if the river and watershed is normally frozen.
- Annual. Natural river flow rates may vary annually due to natural changes in regional weather patterns that result in wet or dry years within specific watersheds.
- Climatic. River flows may also rise and fall over longer time periods in response to decadal- or longer-scale (natural) climatic fluctuations.
- Floods. A flood is a temporary rise in water level. As discussed in Chapter 7, although most floods are natural phenomena, they are generally not considered part of the ordinary condition if they exceed a certain threshold (discussed in Chapter 7). Floods are not considered for most aspects of navigability determinations. The differences between seasonal high flows and floods are also discussed in Chapters 4 and 7.
- Drought. Most droughts are naturally occurring declines in water level. As discussed in Chapter 7, unusual droughts are generally not considered part of the ordinary flow condition, and not considered for most aspects of a navigability determination. The differences between seasonal or other ordinary low flows and an unusual drought are also discussed in Chapter 7.
- Freeze. In some areas, winter weather normally causes some rivers to freeze, putting a stop to any boating,[32] and in some cases, runoff. The existence of a seasonally frozen river does not preclude a finding of navigability if the river is navigable during other parts of the year (e.g., Gulkana River, Mosquito Fork, Knik River).

[32] I am not aware of any case where "trade and travel on water" was asserted to include modes of trade and travel on frozen rivers or other iced-over water bodies.

- Dry. In some areas, summer weather normally causes some rivers to go partially or completely dry, limiting or ending the potential for boating. The existence of a seasonally dry river should not preclude a finding of navigability if the river is ordinarily navigable during other parts of the year.

Therefore, navigability determinations should be based on the understanding that the rates of river flow naturally vary over time, on both short and long time scales, with consequent changes in the boating conditions on the river. It would be unrealistic and unscientific to assert that some level of flow variability was not ordinary and natural.

Characterizing the Natural River Flow Variability

The more common measures of natural river flow are described below.

- Mean Discharge. The mean discharge is the average of all discharge measurements over a given period (Figure 33). The most common time periods considered are annual,[33] monthly, and daily (Figure 34), although mean flow rates could also be computed for other time periods such as a boating or calendar (spring, summer, fall, winter) season.
    - Mean Annual Discharge. This value is typically computed by averaging the individual daily or monthly discharge measurements in a given year, or over a multi-year period of interest.[34]
    - Mean Monthly Discharge. This value is typically computed by averaging the individual daily discharge measurements in a given month of the year, or over a multi-year period of interest using data only from that month of each year. Plots of the long-term mean monthly discharge can be useful depictions of the ordinary seasonal fluctuation in flow rates.
    - Mean Daily Discharge. This value is typically reported on US Geological Survey gauge sites and data summaries, and is computed by averaging the instantaneous discharge measurements for that day. Mean daily discharge may also be the long-term average flow rate for that particular day of all the years in the period of record. Plots of the long-term mean daily discharge can be useful depictions of the ordinary seasonal fluctuation in flow rates, and may be slightly more accurate than monthly flow plots because they are less bound by calendar month-based grouping of the data.

[33] Some data sources report the mean annual flow for the "water year" rather than the calendar year. A water year extends from October 1 to September 30 of the following calendar year, e.g., October 1, 2016 to September 30, 2017. Over long time periods, the differences between the mean of calendar years versus water years is inconsequential for navigability determinations, but caution should always be used when comparing data sets based on different data groupings to reduce confusion.

[34] In some cases, the mean (average) of a listing of mean annual discharges is reported, which can result in a different value than the long-term mean annual discharge computed from the mean of the daily discharges for the entire period of all years of data considered. While such differences are unlikely to be significant for a navigability determination, it is best to clarify what data set is being averaged to avoid confusion and unnecessary arguments.

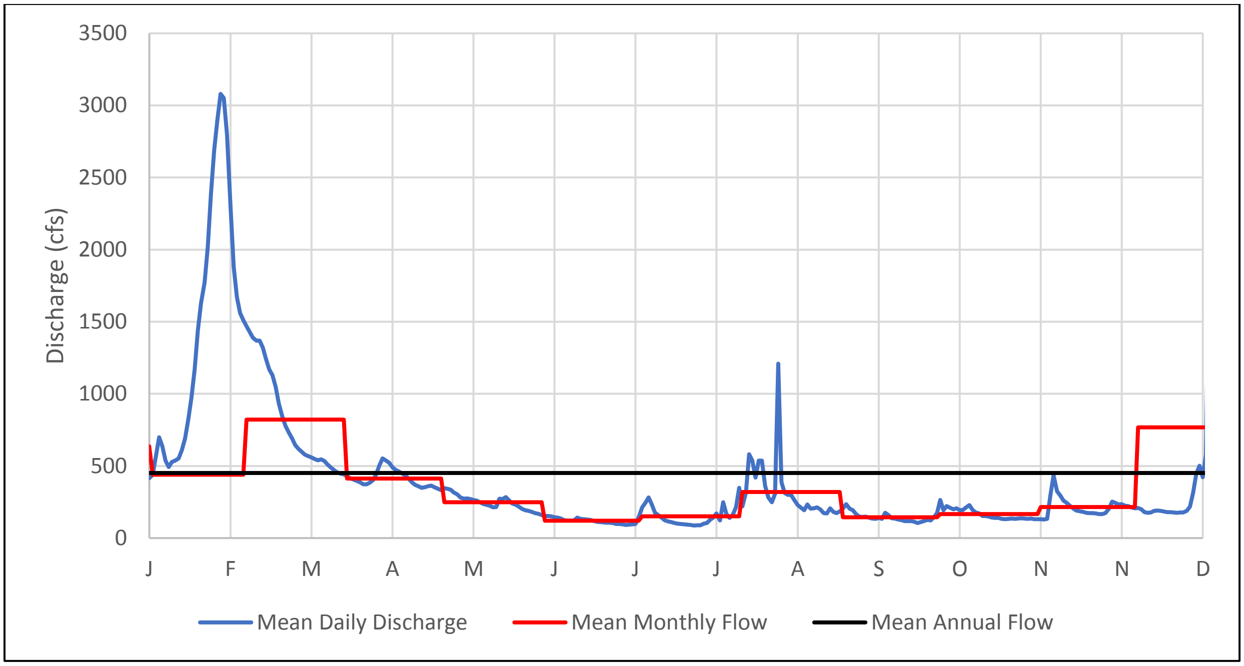

Figure 33. Example plot of mean annual, monthly, daily discharge for a single year (Salt River near Roosevelt, 2016 data).

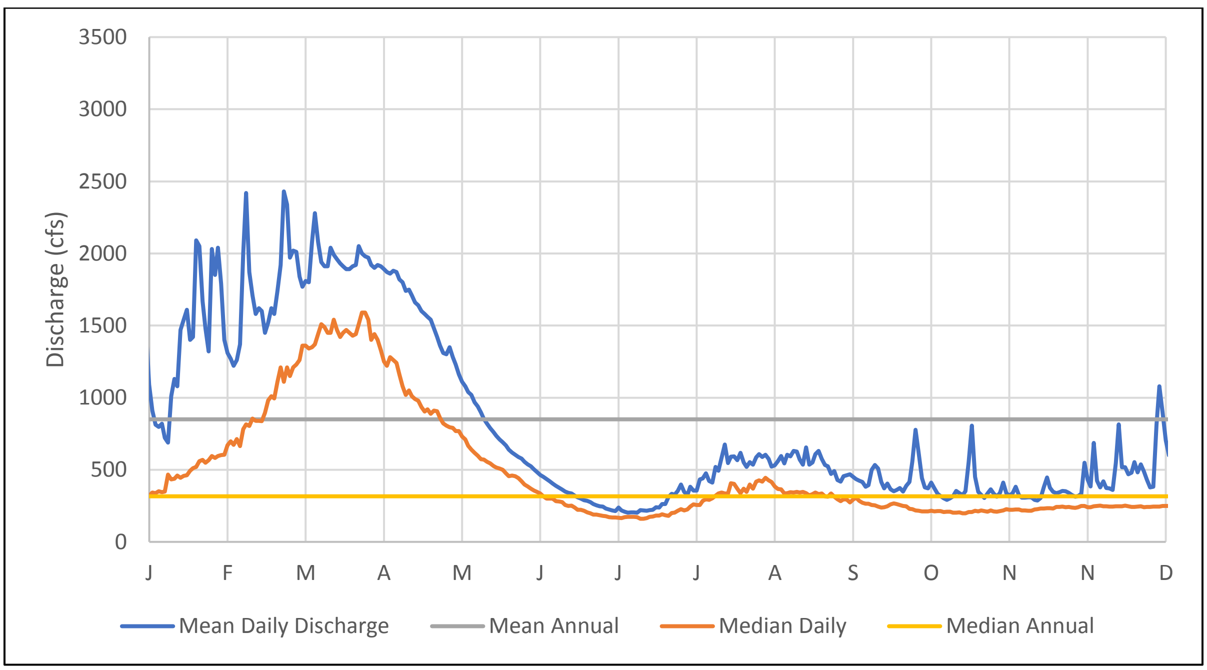

Figure 34. Plot of median mean annual daily discharge for a period of record (Salt River near Roosevelt, 1913-2016).

- Median Discharge. The median discharge is the flow rate for which half the discharge measurements are higher, and half the measurements are lower. Median flow rates can be computed for annual, monthly, and daily discharges (Figure 34).

- Mean vs. Median Discharge. There are some noteworthy differences between use of mean and median discharges, including the following:

- Mean Annual Discharge. The mean annual discharge is the most commonly used flow descriptor in a variety of legal and technical venues, and is often the most readily available flow value. Thus, it is often used when comparing streams from different locations when only a single flow rate is desired.
- Arid Regions. In arid regions and drylands, where river flows are ordinarily low or where rivers dry up seasonally, it is not uncommon for floods to convey a significant percentage of the annual flow volume or for high flows to be concentrated within a relatively small portion of the year. In such situations, the annual median discharge will be less than the annual mean discharge and will be a better representation of the ordinary flow condition, if only a single flow value is used to describe the entire flow record of the river.[35]

- Mean Daily Discharge. For most modern US Geological Survey (USGS) gauging stations, flow rates are measured at 15 minute increments throughout each day.[36] These "instantaneous" values are then averaged for each day and reported as the mean daily discharge. This averaging process results in some daily highs (and lows) not being represented in the most commonly used data sets. From the perspective of navigability assessments, particularly on rivers subject to flash floods that have durations of few hours, the mean daily may be slightly inflated by the averaging in of brief floods. From a practical sense, such short floods are inherently rare, particularly on large river systems, and even more rarely exceed the ordinary high-water mark, making the impact on a navigability assessment negligible.

- Flow Duration Curve. A flow duration curve is a plot of discharge versus the percent of time that flow rate is equaled or exceeded, and is another way of characterizing the variability of river flow. Typically, flow duration curves are constructed using mean daily discharge data over the entire period of record, but it would possible to construct flow duration curves for any time period, such as a boating season, spring runoff, the open water period (for rivers that freeze in winter), or even for a specific calendar day of the year. The 50% value on a flow duration curve is equivalent to the median discharge. Flow duration data also demonstrate how most flood peaks are well outside the range of typical flow conditions in a river (Figure 35).

  On rivers where there is significant seasonal fluctuation of flow, a flow duration curves constructed from flow data from the entire year may misrepresent ordinary flow conditions during the high and low flow periods, especially where the high or low flow conditions are not boatable. In such cases, it may be necessary to construct flow duration curves from data just from the boating season or the high flow season.

  One of the things that stands out on a flow duration curve is how rare floods are from a percent-of-time perspective. The 1% flow rate on a flow duration curve is normally well below the peak

[35] For example, consider a data set of the following values: 10, 10, 10, 15, 15, 30, 40, 2000. For these data, the mean = 302, and the median = 15.

[36] Mean daily discharge values reported in historical gauge records may have been based on longer or unknown time increments, or may have been based on a single reading each day. Many modern gauges record flow rates at less than 15 minute increments during rapidly rising or falling hydrographs.

discharge of even a small flood like the 2-year event (Figure 35). This fact becomes important when trying to define the ordinary range of flow (Chapter 7).

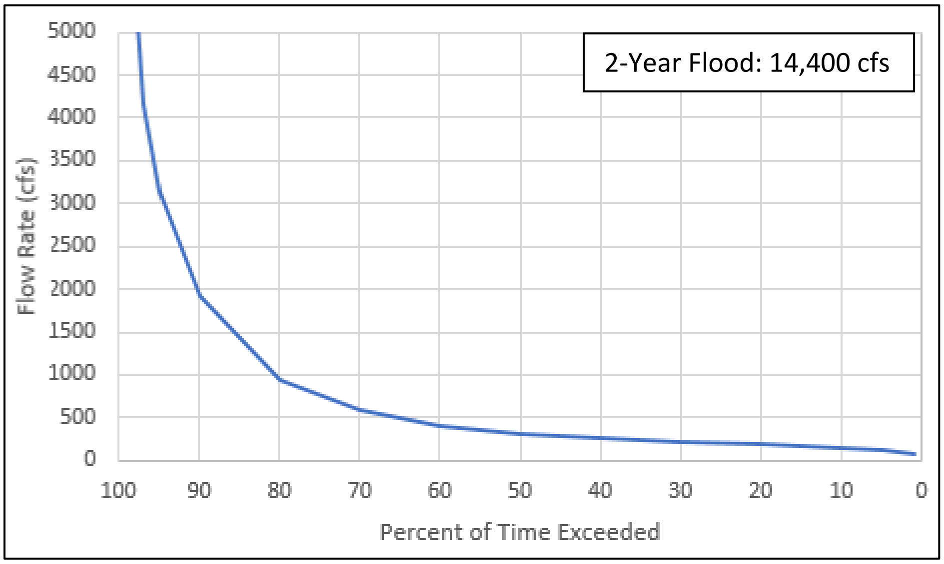

Figure 35. Flow Duration Curve (Salt River near Roosevelt, 1913-2017)

- Base Flow. Base flow is the water carried by a river that is not the direct result of precipitation or unusual snowmelt, and consists mostly of discharge from the subsurface from springs, ground water, and seepage from the lands adjacent the river bottom (Figure 36). It is also called sustained runoff, dry weather runoff, or fair-weather runoff. Base flow fluctuates seasonally and episodically in response to watershed, climate, and subsurface moisture conditions. Base flow in any reach includes the river flow from upstream stream reaches that is not the direct result of precipitation; that is, upstream inflows are not normally excluded from the base flow.

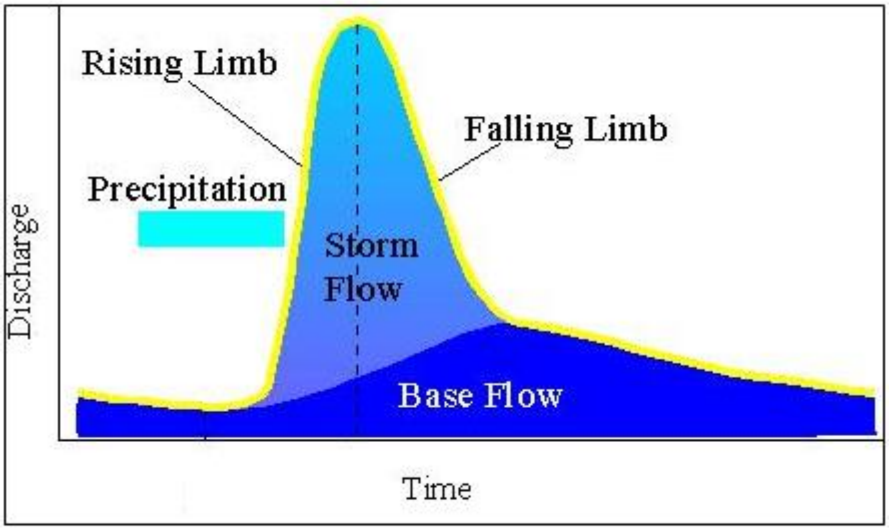

Figure 36. Illustration of base flow relative to a flood hydrograph.

Human Impacts on Flow Rate – Non-Natural Flow

Humans can impact river flow rates directly or indirectly. The following are some of the more common types of human impacts on river flow rates (also see Table 2 in Chapter 3):

- Dams. There are several types of dams, all of which change flow rates for downstream river segments. Large dams, or a series of small or diversion dams, have the potential to completely dry up a river, as was the case for the lower Salt River in Arizona addressed in the Winkleman v. ANSAC case. Because of engineering design standards and water rights monitoring requirements, the alterations in downstream flows are usually computed and/or gauged, or can be determined, to make reasonable estimates of pre-dam flow rates. Some common types of dams include the following:
    - *Water supply dams* impound river water and release it to meet the needs of downstream water users. Such dams typically release the natural volume of water downstream, but may change the seasonality of runoff, e.g., storing and reducing high spring runoff, then releasing and increasing normally low mid-summer flows. These types of dams tend to impact low flow (i.e., ordinary) rates more than flood flow rates, but also commonly reduce or eliminate many flood peaks.
    - *Flood control dams*[37] may store only flood water, and therefore may have less impact on low flows (i.e., ordinary) rates than water supply dams.
    - *Diversion dams* may divert all or part of a river's ordinary and/or base flow into an off-river canal or water storage area, but have a decreasing relative impact as river flow rates exceed the dams' diversion capacity.

  Alteration of the natural river flow by water storage, diversion, and release may also have secondary impacts on river flows due to changes in riparian habitat, sediment supply, ground water levels, and water quality, which in turn may result in changes to the river channel that also affect navigability.
- Water Transfers. Inter-basin transfers of river water increase or decrease a river's base flow and low flow rates, depending whether the transfer is into or out of the river. The amount of water transferred is typically measured for water supply and water rights purposes, and can generally be determined to estimate the pre-transfer flow rates on all directly affected streams.
- Irrigation/Diversions. Diversions for irrigation or other consumptive uses reduce river flow rates. Low flow and base flow are typically impacted the most, but much higher flow rates may also be depleted and in some cases, diversions could completely dry up a river except during the largest floods. Estimating the impact of diversions on downstream depleted flows is complicated and subject to significant engineering judgment and subjectivity. Some irrigation companies do not keep (or will not release) precise records of the actual amount of water diverted at the main river or at all turn outs from the canals, nor is the diversion capacity and performance of the diversion structure necessarily well known. Furthermore, irrigation return flows are typically not measured or reported and may vary significantly depending on the irrigation methods, the individual user, the type of crop(s) being irrigated, weather conditions, variations in acreages under irrigation from year to year, and other factors. In some cases, part or all the irrigation return flows are the result of groundwater pumping or water transfers, and are not directly

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[37] Many dams have both water supply and flood control purposes.

related to any irrigation diversion from the local river. Finally, some agricultural return flows to the river are caused by draining of farmland with high-water tables.

- Ground Water Withdrawal. Excessive ground water pumping can lower the water table, changing a gaining stream to a losing stream. Such losses will impact base flows and low flows more significantly than high flows, where the impacts are typically negligible.
- Sewage Effluent. In some cases, treated effluent is released into rivers, creating or increasing base flow and low flow rates above the natural levels, and in other cases restoring some of the losses from other depletions. In many cases, the rates of effluent discharges will be monitored at their source.
- Storm Water and Dry Weather Flows. Storm water and dry weather flows[38] from highly urbanized areas can be a source of increased non-natural base flow. Increased impervious cover in developed areas will shed more water than the natural watershed and increase the volume and frequency of inflows to some urban rivers. This source of potential inflow is reduced somewhat where storm water and first flush retention policies are enforced, but may have altered low flow streamflow measurements before such policies were enacted. Estimating the magnitude of such dry weather discharges for ungauged sources is difficult.
- Watershed Land Use and Vegetative Cover. Changes in land use or vegetative cover type due to urbanization, deforestation, conversion of rangeland to agriculture, mass grading, influx of invasive plant species, or over-grazing can significantly change how runoff occurs in a river system. The changes can affect the entire hydrograph, from base flows to flood peaks. In general, human impacts on watershed land use and vegetative cover tends to decrease base flows and cause high flows to be flashier (less duration), which can significantly and adversely impact channel stability, resulting in substantive changes to a river's active channel.
- Floodplain Encroachment and River Channelization. In most cases, encroachment and channelization do not affect base flow or low flows, but they may significantly increase flood peaks and have other indirect impacts on a river's navigability characteristics resulting from directly or indirectly altering the river morphology.
- Mining. In-stream mining, especially large-scale aggregate mining is usually more of an impact to stream morphology than to flow rates, unless there is consumptive use of river water, in which case the affects would be similar to other diversions or water transfers.
- Climate Change. The time scale for natural climate change is typically too slow to impact navigability determinations, other than normal decadal scale wet and dry cycles which may be reflected in the period of record for available stream gauges. It is possible that human-induced climate change has or will impact flow rates to a degree that impacts the navigability of some rivers, but at present there are not sufficient data from which to make such a determination. It is most likely that human-induced climate changes that have occurred between the date of Statehood and the present have caused relatively minor differences in the boatability of otherwise natural rivers, rather than have caused a transformation of a navigable river to a non-

[38] Dry weather flows from urban areas are the result of over-watering landscape, draining swimming pools, leaking pipes, and a variety of other sources. Such flows are typically small, but in some cases, are significant. For example, according to USGS streamflow measurements, the mean annual discharge in Las Vegas Wash (# 09419800, LVW below Lake Las Vegas) increased from 50 cfs in 1970 to over 300 cfs by 2005, primarily due to dry weather discharges from the Las Vegas metropolitan area.

navigable one, or vice-versa. However, where evidence exists that human-caused climate change has impacted boatability, it should be examined on a reach-specific basis.

Indirect human impacts on natural flow rates can be difficult to estimate accurately because there are complex interconnections between the various impacts. For example, urbanization may increase storm water and dry weather flows to a nearby river, and add effluent flow sources, but ground water pumping, diversion, and consumptive water use will decrease runoff rates.

Summary

Flow rates on natural rivers vary as a result of natural changes in precipitation, weather, and climate, which cause seasons of high and low flow, as well as episodic increases in normal flow. The natural variation of river flow can be quantified by reporting annual and seasonal mean and median flow rates. Human activities can significantly alter the ordinary range of natural river flow.

Chapter 7:

Ordinary Flow Rate of a River

In Winkleman v. ANSAC, the Arizona Court of Appeals relied on Black's Law Dictionary for their definition of "ordinary" as follows:

> *"Occurring in the regular course of events; normal; usual."*

The Court specifically noted that ordinary conditions exclude "drought" or "exceptional conditions in times of temporary high-water," and held that ordinary means the "conditions prevailing throughout the greater part of the year." Essentially, the Court's definition explicitly excludes "exceptional" floods and "unusual" droughts, and implicitly includes everything else in between, if those conditions are natural. On natural rivers, "everything else" includes the normal, non-extraordinary seasonal and annual fluctuations of flow. That is, the flow rates that occur between the onset of flood stage and the beginning of unusual drought conditions constitute the range of the ordinary conditions. That there is a range of ordinary flow conditions on natural rivers, rather than a single flow rate, was discussed in more detail in Chapter 6. However, other than the Winkleman v. ANSAC Decision, there is little direction from the courts as to what constitutes the range of ordinary flow rates.

In this Chapter, a scientific basis for the natural range of flows that should be considered "ordinary" is presented.

The Upper Limit of Ordinary: Onset of Flooding

Past Court decisions dictate that boating on floods is to be excluded from navigability determinations (Daniel Ball; Oklahoma v. Texas). Therefore, the onset of flood conditions must be the upper limit of the range of ordinary flow rates used to determine if a river is navigable. Therefore, it is necessary to define what flow rate constitutes a "flood," and distinguish that from other natural fluctuations in flow rates, as described in Chapter 6. Obviously, there is no one numerical value for a flow rate that indicates flooding that applies universally to all rivers. The flood/ordinary flow rate determination must be made for each river individually.

A flood is defined as "a temporary rise in water level that inundates ordinarily dry land" (FEMA, 2011). This definition is sufficient for most navigability determinations, though the terms "temporary" and "ordinarily" leave some ambiguity. In addition, some arid and semi-arid region streams are ordinarily dry, making every flow on those rivers a "flood," according to an overly simplistic and strict reading of the definition, an interpretation which is clearly incorrect, since a few cubic feet per second of runoff on a normally dry stream bed wouldn't be considered a flood.[39] Similarly, any rise above base flow would inundate bars and beaches, that a party could argue were "ordinarily" dry. The word "flood" carries a connotation of a significant event, or inundation of land one would not expect to see inundated on a regular basis.

As discussed in Chapters 3 and 4, the ordinary high-water mark is a naturally occurring, physical feature that can be readily identified on a natural river, and which can be used to define the threshold between

[39] One could also make the argument that any flow on a dry river bed was a "flood," but that it was "ordinary" flooding (a.k.a., high flow) until it exceeded the ordinary high water mark.

flood (non-ordinary) and non-flood (i.e., ordinary) flows unique to that river. That is, the flow rate that causes the river to overtop its ordinary high-water mark indicates the onset of exceptional flooding and is the upper limit of the range of ordinary flows.

Seasonal high flows that do not exceed the ordinary high-water mark should, therefore, be considered ordinary, and part of the natural fluctuation of river flow to be evaluated in a navigability determination. Some unusual seasonal flows may exceed the ordinary high-water mark temporarily, and would thus not be considered in the ordinary range of flow. However, the seasonal high flows that occur regularly will contribute to the formation of the physical feature that is the ordinary high-water mark, and by definition will not exceed that level. By this definition, ordinary means events that occur frequently enough to create a semi-permanent feature on the landscape, the ordinary high water mark.

Flows exceeding the ordinary high-water mark elevation may only occur for a small portion of any given year, or may not occur at all in a given year, and may be equivalent to a flow rate that is well above the 99% flow on an annual flow duration curve. Scientific literature concerned with ordinary high-water marks includes significant discussion about the recurrence interval of the ordinary high-water mark flood. In temperate and humid climates, the ordinary high-water mark is thought by many river scientists to be equivalent to about a 1.5-year event (Rosgen, 1996). However, in dry lands and on flood-dominated streams in the arid west, the ordinary high-water mark may be equivalent to a less frequent event (Williams, 1978). This difference is due in part to the high flood ratios (Q100/Q2) on dryland rivers, as well as the long persistence of flood scars on the landscape and slow rates of recovery in poorly-vegetated arid regions. Therefore, in dry regions like Arizona, use of the ordinary high-water mark event as the upper limit may cause the upper limit of the ordinary range to be a rarer event than it is in humid regions.

Similarly, on rivers where there are major seasonal differences in flow rates, but where the river flows throughout the year, use of the ordinary high-water mark as the upper limit of the ordinary range of flows may overestimate the upper limit of ordinary during the dry season. In such cases, it may be helpful to identify the occurrence of dry season flow events that exceed the 99% flow duration but that are less than the flow rate that reaches the ordinary high-water mark. This distinction would provide a more complete understanding of ordinary conditions, though it would not be likely to have any impact on river conditions that are ordinarily boated.

Nevertheless, despite the potential to overestimate the upper limit of the ordinary range when using the ordinary high-water mark in drylands, the advantages are significant and include the following:

(1) Lack of an Alternative. There is no established scientific or legal basis for selecting any other legal upper limit, making use of any other standard subjective.
(2) Standard of Practice. There is established precedent and a standard of practice relating to determination of ordinary high-water marks that is relied on in both the scientific and legal communities.
(3) Nexus of Terminology. The use of the adjective “ordinary” to describe flow conditions in navigability determinations and as the legal boundary of public ownership of navigable rivers is propbably not coincidental, and sets a precedent for distinguishing ordinary and non-ordinary high-water.
(4) Natural, Physical Feature. The ordinary high-water mark is naturally-occurring, physical feature formed by the river itself as a result of flows frequent enough to leave a permanent,

> recognizable mark on the landscape. The ordinary high-water mark separates the river landform that is dominated by fluvial processes from upland landforms that are not directly shaped by river processes.

Therefore, the ordinary high-water mark[40] is recommended as the upper limit of the range of ordinary flows.

The Lower Limit of Ordinary: Onset of Drought

The Arizona Court of Appeals also established "unusual drought" as the low end of the range of ordinary flow conditions to be used to determine navigability. The fact that the court used the phrase "unusual drought," suggests that they intended to include some types or definitions of drought within the range of ordinary flows.

The term drought has distinct definitions dependent on the scientific discipline under consideration. For example, the US Geological Survey (USGS, undated) distinguishes between meteorological drought (abnormally dry weather), agricultural drought (shortage of precipitation that adversely affects crops), and hydrologic drought (below average water content in rivers). Given that title navigability is primarily concerned with rivers, the latter definition is probably most relevant. However, the Arizona Court of Appeals used the phrase "unusual drought," which suggests that they had something more rare in mind than the USGS' "below average" criterion for hydrologic drought.[41] Use of an average flow rate as the lower limit would not meet the Court's additional description of "conditions prevailing throughout the greater part of the year," since rivers flow below their average at least 50 percent of the time.

Flow duration data (Figure 35) could also be used to describe the low end of ordinary. As described in Chapter 6, use of seasonally adjusted, or even daily flow duration data, would provide more accurate information than annual flow duration data. However, there is no legal or scientific precedent that relates a specific flow duration, i.e., 10%, 5%, 1%, to the standard of an "unusual" drought, making the selection of any specific flow duration somewhat subjective.

"Base flow" is the water carried by a river that is not the direct result of precipitation or snowmelt, and consists mostly of discharge from the subsurface from springs, ground water, and seepage from the lands adjacent the river bottom (Figure 36). Base flow represents a river's discharge rate without runoff contributed from rainstorms or other forms of precipitation. In practice, base flow varies seasonally, annually, as well as on longer time scales in response to wet/dry climatic cycles, i.e., "unusual drought" conditions. Annual and longer base flow fluctuations are probably less important to navigability determinations than normal seasonal fluctuations. Seasonal and annual base flow is relatively easy to compute if continuous record gauge data are available. Therefore, base flow is recommended as the lower limit of the range of ordinary flow conditions for navigability determinations.

If sufficient data are available, base flow should be computed on a daily basis, using the median daily base flow, so that normal seasonal fluctuations in base flow are represented. Lacking such data, annual

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[40] Note that the ordinary high-water mark for current (modern) conditions may not reflect the ordinary high-water mark level for the undisturbed, natural (historical) condition of the watercourse.
[41] Presumably, the USGS' "below average" criterion is meant to apply to a seasonal or daily average, rather than an annual average flow rate.

or boating season base flow estimates would probably suffice for the purposes of a navigability determination.

Use of seasonal base flow as the lower limit of the range of ordinary likely results in a flow rate somewhat higher than the “unusual drought” condition described by the Arizona Court of Appeals. However, the following justify use of seasonal base flow, as opposed to trying to compute a different flow rate that describes unusual drought conditions:

- No Definition of Unusual. There is no established scientific or legal definition for what constitutes a level of “unusual” drought. The definition of the “drought” is inherently subjective. Trying to add the descriptor of “unusual” only increases the level of subjectivity.
- Available Data. Streamflow data are available for many streams from which base flow can be computed.
- No Data. For streams that lack systematic gauge data, estimates of base flow can be made from field observations, historical stream descriptions, or regional runoff modeling techniques.
- Seasonal fluctuation. Use of base flow allows consideration of seasonal fluctuation in stream flow rates rather than a single minimum flow rate that could exceed or fall below seasonal rates.
- Standard of Practice. There are published guidelines for computing base flow from which a standard of practice can be established (Chow, Maidment, and Mays, 1988), facilitating its use in a court setting.

From the perspective of a navigability determination, establishing an exact numerical threshold of flow, either as base flow or a specific flow duration rate, that defines the onset of “unusual drought” conditions on a river is useful for presenting flow data in a court setting, but is not critical for the navigability determination itself because a stream need not be susceptible to navigation during the entire year. The low end of boatability of a river is defined by the flow rate at which boats can be used, which may be well above the base flow rate on some rivers. However, if it can be show that a river is boatable at base flow (or in unusual drought conditions), then that fact will be very useful for the navigability determination. Therefore, establishing a criterion for the low end of the ordinary range of flow is more of a convenience for the scientists charged with collecting and presenting data about ordinary river conditions, than a necessity for the judicial bodies rendering the navigability determination.

The upper and lower limits of the ordinary range of flow alone do not fully characterize a river’s ordinary condition. Information about the frequency, duration, reliability, and predictability of boatable and non-boatable flow rates within the ordinary range of flow is also required, as discussed below.

Erratic and Unpredictable Flows

In Arizona navigability cases, the normal flow in some rivers was characterized by some parties as being so “erratic” and/or “unpredictable” that it made them not navigable. In the Montana PPL case, the US Supreme Court noted that the boatable flow rates should not be “so brief that it is not a commercial reality.” The Supreme Court did not quantify what it meant by “so brief” or what flow duration was sufficient to demonstrate a commercial reality, nor does any state law or any navigability court define the words erratic or unpredictable. Some clues to the meaning of what constitutes “too brief” can be found in other navigability cases:

- Missouri, Madison, Clark Fork Rivers (PPL Montana v. Montana, 2012). The Supreme Court also noted that a river "need not be susceptible of navigation at every point during the year" and that "seasonal variations of water depth" are expected.
- Gulkana River (Alaska v. United States, 9th Circuit, 1987). In this case the court ruled that seasonal commercial recreational boating was sufficient to demonstrate navigability on a river that is frozen over for large parts of the year.
- Weber River (Utah Stream Access Coalition v. Park, 2015). Here, the court determined that floating logs only during the spring snowmelt period was sufficient evidence to prove navigability, even though a sufficient snowmelt flow did not occur every year.

Therefore, it is at least known that the "so brief" criterion does not preclude navigability decisions based on flows as short as seasonal high-water such as the spring snow melt period, which could be as short as a few weeks.

It is also clear to anyone with experience on dryland rivers that there are in fact erratic, unpredictable flows on some rivers that are too brief to support "trade and travel on water" or to allow the river to serve as a "highway of commerce." If a river's ordinary flow is so erratic or unpredictable that not even seasonal boating or log floating could not or did not occur regularly, then the river is not navigable for title purposes. Therefore, it is important to determine if a river's ordinary flow condition is too erratic or unpredictable for boating

To better quantify what the US Supreme Court's "too brief" criterion might mean, a range of possible meanings is listed below, at least from the perspective of a river scientist. To date, no court has firmly established any legal definition of the required frequency, duration, predictability of flow. Lacking any statutory, court-determined, or scientific definitions for the terms, Webster's Seventh New Collegiate Dictionary provides the following definitions:

- <u>Brief</u> means "of short duration."
- <u>Erratic</u> means "deviating from what is ordinary or standard" or "acting, moving, or changing in ways that are not expected or usual; not consistent or regular."
- <u>Unpredictable</u> means "not able to be foretold on the basis of observation, experience or scientific reason."

One of the first things that stands out in these dictionary definitions, is that erratic means not <u>*ordinary*</u>. Thus, by definition, any erratic flows should not be considered in a navigability determination because erratic flows are not the ordinary condition of the river. Recognizing the incongruity of characterizing a river's ordinary condition as non-ordinary (i.e., erratic), a more accurate description of what is meant by erratic flow is that the only time a river could be boated was during unpredictable, short-duration flow events, and that absent such flows the river was unboatable. That is, the ordinary flow condition of the river is unboatable flow rates.

To further clarify the Court's "too brief" criterion, consider what is definitively known and not known. This includes the following:

- Floods. Boating on "unusual" floods is not evidence of navigability because it occurs outside the range of ordinary flow conditions. Therefore, if it is only the unusual floods that make river conditions erratic or unpredictable, and unboatable conditions exist when the river is not in flood, such erratic or unpredictable flood events are irrelevant to a navigability determination. Only non-flood flow conditions below the ordinary high-water mark event should be considered. Furthermore, since all natural rivers experience floods, and many rivers that experience extreme floods relative to the ordinary range of flow (e.g., the Colorado River, the Knik River) have been found navigable, the mere presence of occasional floods do not preclude a navigability finding.

- Seasonal Flow Fluctuation. The US Supreme Court has established that regular seasonal increases in water level are both expected and a potential basis for a navigability finding (PPL Montana; United States v. Utah). Water levels on natural rivers ordinarily rise during spring snowmelt or during rainy seasons such as Arizona's summer monsoon. Therefore, such ordinary, seasonal fluctuations should not be considered evidence of erratic or unpredictable flow, since they are expected and occur during regular times of the year. The fact that the exact calendar dates for the beginning, duration and end of seasonal fluctuations cannot be precisely known is not evidence of erratic or unpredictable flow. It is also possible for an erratic, unpredictable event to occur within the normal period of seasonal high flow, but such events should be excluded from the navigability determination, unless they occur with such frequency to make boating possible.

- Duration of Flow. A useful measure of whether a specific flow event is short enough to be considered erratic is to compare the duration of flow, or more specifically, the duration of the boatable portion of the flow event, to the time it would take to boat a river reach. If the period of elevated, boatable water levels significantly exceeds the length of time of a typical boat trip, then it should not be considered erratic with respect to boating. For example, if an ordinary high-water event typically lasts for a week or more, but the river segment can be boated in a day or less, then there is ample time for a boat trip to be planned and executed and the event should not be considered erratic. Conversely, if a typical high-water event lasts no more than a few hours, and it would take a day or more to boat the river segment, then the event would most likely be considered erratic and not supportive of a navigability finding.

- Frequency of Flow. Another measure of whether a river's ordinary flow condition could be considered erratic is in the frequency and timing of short-duration flow events. Consider a river that is not boatable at its base flow rates, but which becomes boatable when the water level rises above base level flows. In such a situation, how often such water level rises occur (in addition to their duration, as described above) would be a factor in determining whether those flows could be defined as erratic or unpredictable. If such rises were clustered seasonally (e.g., during a summer monsoon season) rather than distributed randomly throughout the year, they would be less likely to be considered erratic and would be more predictable. Similarly, if the rises in water level occurred more often than not, rather than only a few times per year, they would be less likely to be considered erratic and unpredictable.[42]

[42] That is, a boater might not be able to boat on any given day, but if the boater waited a day or two, there would be a reasonable expectation that a boatable flow would occur throughout the boating season.

For example, stream gauge records from some ephemeral rivers in Arizona indicate that these normally dry rivers experience only a handful of boatable flow rates in any given year, and in some years, may not experience any such events. Most high flows occur during the summer monsoon season which lasts for about three months, with any individual event likely to have a duration of an hour or less to less than one day. For the purposes of a navigability determination, such a river should be considered erratic and unpredictable if the base flows are unboatable, and boatable conditions only occur during the short-duration events.

- Predictability. Predictability is not equivalent to certainty. For example, the exact calendar date of snowmelt runoff sufficient for floating logs on Utah's navigable Weber River was never known for certain, but it was certainly predictable that such flows would occur at some point in the spring in most years. Likewise, the precise date when the navigable Gulkana River thawed was never a certainty, nor did it begin on the same day every year, but it was certainly predictable that the river would thaw eventually and that boatable flows would occur. The mere existence of a flow duration curve or a chart of average monthly flows with seasonal variation is testimony to at least some level of the predictability of river flows. A graph of historical flow data from a river with truly unpredictable flow rates would have no seasonal variation (i.e., uniform throughout the year).

- Reliability. For navigability determinations, unreliability may be a better word than unpredictability when it comes to the commercial reality of trade and travel on a river. The reliability of boatable river flows increases with their frequency, duration, and seasonality. However, it is worth noting that the degree of reliability required for trade and travel varies with the type of activity. Not all river activities require the reliability needed to compete with commercial delivery services like FEDEX or UPS, or even the level of reliability that exists for shipping on the Mississippi River.[43] Particularly for some historical types of river uses, such as trapping, logging, and mining, or for uses such as commercial recreation or guiding, it is enough to know that boatable flows will occur within a general window of time.

- Flow Duration Curves. If gauged streamflow data exist, it is usually possible to construct a flow duration curve that depicts the time that specific flow rates are equaled or exceeded (Figure 35). Such curves, in conjunction with boating data, can be used to depict the amount of time during the year (or season) where boatable flows exist and whether boatable flow rates ordinarily occur within predictable, expected, non-erratic ranges. If boatable flow rates occur most of the time, i.e., ordinarily, according to the flow duration curve, then the occurrence of a few erratic, non-boatable flows should not preclude a navigability finding. The flow duration curve, in conjunction with graphs of seasonal or monthly flow rates, are useful for identifying whether boatable flows are predictable or not, since they characterize the percent of time that given flow rates occur. For example, if it can be demonstrated that a river can be reliably boated at flow rates ranging from X cfs to Y cfs, and that the flow duration curve indicates that those flow

[43] Note that even on obviously navigable rivers like the Mississippi, the government has invested significant funds over many decades to improve the natural reliability and reduce the natural difficulty of navigation by constructing water control dams, locks, and river training structures, as well as conducting massive dredging operations.

rates occur 70 percent of the time, then the boatable period for that river should probably not be considered erratic or unpredictable (Figure 37).

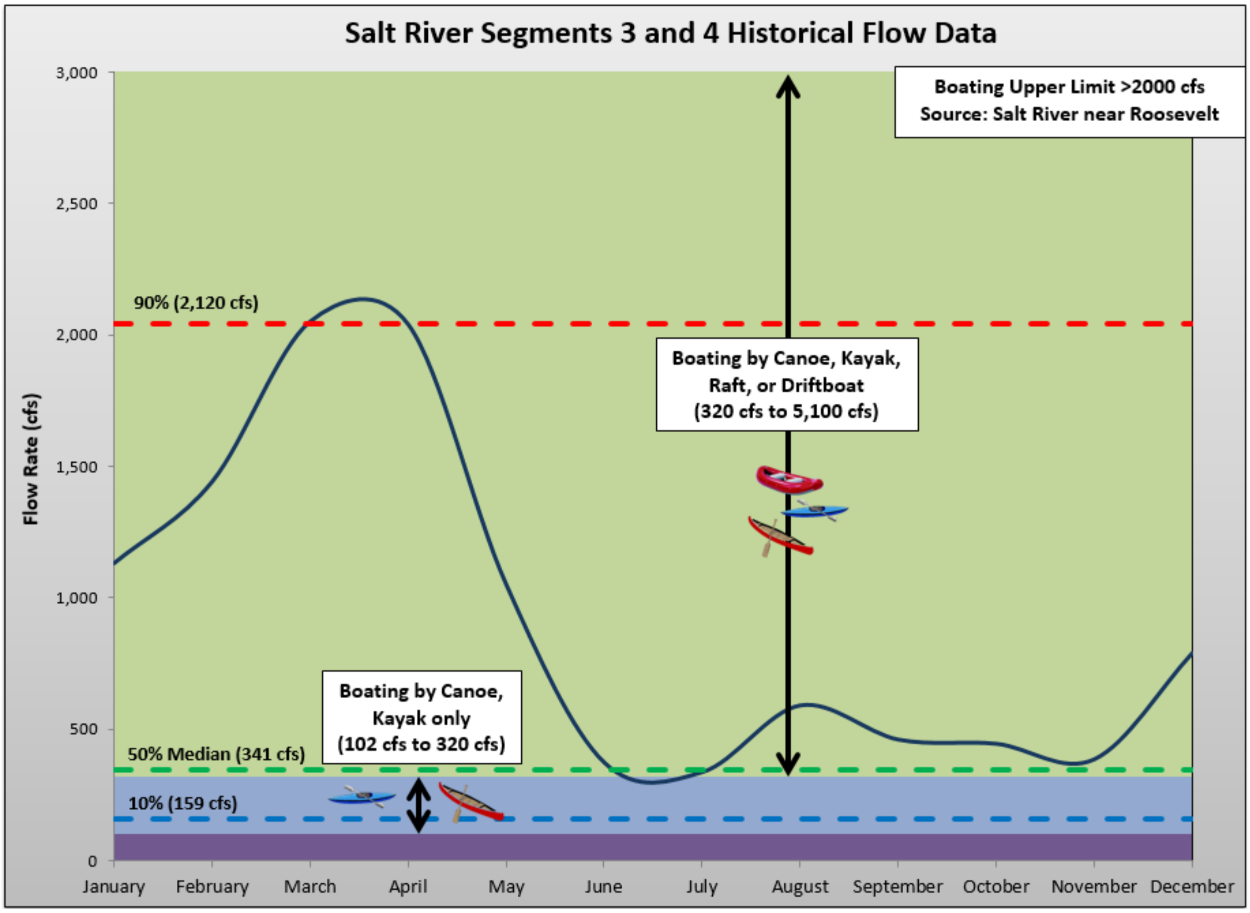

Figure 37. Flow duration and boatable flow rates.

- Daily Discharge Plots. If a river was truly erratic with unpredictable flow events, then a flow duration curve (Figure 35) or a plot of average monthly flow (Figure 33) might not tell the full story of the occurrence of boatable flow rates due to the averaging of flow annual, monthly, daily flow data required to generate the curves. In such cases, it is necessary to supplement the record with a day-by-day (or instantaneous) plot of boatable and unboatable flow rates over the length of the gauge record to document the long-term frequency, duration, and (un)reliability of the occurrence of boatable flows.

- Flash Floods. The National Weather Service (undated) defines a flash flood as "flooding that begins within 6 hours, and often within 3 hours, of the heavy rainfall (or other cause)." Flash floods that exceed the ordinary high-water mark are more likely to occur on streams with small watersheds than on large, main stem rivers, due to the limited spatial extent of the high rainfall intensities required to generate flash flooding. Flash floods are rare events, and generally are not part of the ordinary condition of the river. While the potential for flash floods on a particular river system should be noted in the description of the river's ordinary condition, it should be presented with its probability of occurrence so that its importance is not overstated. In addition, the impact of the typical flash flood on a particular river's boatability should also be characterized since not all "flash" floods make any substantive change in boating conditions. On most navigable rivers, the probability of a flash flood impacting boating is so low that it is well outside the range of ordinary conditions and insignificant to a navigability determination. That is, while a flash flood might happen, it would not happen ordinarily.

- Difficulty. For most rivers that are candidates for navigability determinations, except for those that freeze or dry up completely, the seasonal and other ordinary fluctuations in flow rate do not represent a transition from boatable to unboatable conditions. Instead, fluctuating flow levels equate to changes in the ease or difficulty of boating the river segment. In some cases, periods of low water may mean that the boat must be piloted more carefully, that it may bump the river bed more frequently, or that it might even need to be dragged, pushed, or carried over some shallow spots. Alternatively, periods of high-water may require more careful maneuvering through rapids than at lower flow levels, or portages around otherwise boatable locations. Unfortunately, there is no legal or scientific criteria that dictate the minimum or maximum level of difficulty for a navigability determination, although the courts have determined that some difficulty does not prevent a finding of navigability.[44] The issue of difficulty of boating is important, and intersects with other aspects of navigability investigations, but is not fully addressed in this report.

Summary

As described above, flows on natural rivers are not constant, but instead exist within a range of natural fluctuation in response to climate, weather, and other natural phenomena. Therefore, when describing the ordinary range of flow rates for a navigability determination, the flow data should adequately characterize the full range of flow variability from base flow to the ordinary high-water mark flow rate in the river's natural condition, as described in Chapter 6. It is also useful to characterize the amount time, seasonality and characteristics of a river's flow that is outside the range of ordinary flow. To assist the court to address the potential erratic or unpredictable flows, the technical team should also provide as much information as possible on the flows within the range of ordinary flows, such as the duration of non-boatable flow conditions, changes in boating difficulty related to flow rate changes, and accurate data regarding the normal and expect seasonal flow conditions. As always, historical and modern records of known boat use on the river can provide an important reality check on desktop assessments of the boatability of flows within the range of ordinary conditions.

More specific recommendations on how to present such flow data are provided in Chapter 8.

[44] State of Oregon v. Riverfront Protection Assoc., 672 F2d 792 (1982).

Chapter 8:

Determining the Ordinary & Natural Flow Rates: Recommended Methodology

In many cases, alteration of the natural river flow is the most significant human impact on a river's ordinary and natural condition. Therefore, estimating the change in flow rates associated with human impacts is a very important part of the ordinary and natural condition assessment. The methodologies used to estimate a river's natural flow rate depend on the type of available hydrologic data as well as the level of human activity along the river and in the watershed. Therefore, the recommended methodologies outlined in this chapter include the following:

- Gauged Rivers
  - Natural Condition
  - Altered Hydrology
- Ungauged Rivers
  - Natural Condition
  - Altered Hydrology
- Alternative Sources of Flow Data
- Common Problems with Flow Data
- Rating Curves

Because there may be many permutations of the types of available data, river conditions, navigability issues, and other factors, only an outline of the recommended methodology is presented to identify the most salient issues. Application of the recommended methodologies will require site-specific adjustments, as well as considerable judgment and experience.

Gauged Rivers: Natural Condition

Fortunately, most of the larger rivers in the more populated areas of most states have been gauged, with the possible exception of Alaska. In arid regions of the western United States, nearly all the larger perennial and intermittent streams have at least some gauge record that can be used to establish the ordinary range of flow rates. And it is the larger perennial streams that are most likely to be navigable.

If a river and its watershed are determined to be in a natural condition, and there is a reliable gauge with a sufficient length of record, then estimating the ordinary and natural flow rates is a relatively simple exercise in data collection and hydrologic analysis. Flow data pertinent to a navigability determination to be derived from the gauge records were outlined in Chapter 8, and include the mean and median flow rates, seasonal fluctuation in mean and median flow, a flow duration curve, information on base flow, and information relating to floods such as their frequency, magnitude, flashiness, seasonality, and durations. In addition, it may be helpful to examine the gauge records to look for evidence of drought, climatic or hydrologic cycles relative to key periods of history, or other natural changes in flow.

Gauged Rivers: Altered Hydrology

For gauged rivers where the river was or is no longer in its ordinary and natural condition, flow estimates derived from the gauge record may need to be adjusted to account for the impact of human activities on the measured flow rates. In some cases, gauge records prior to the human activities may be sufficiently long to obtain reliable estimates of pre-disturbance flow rates, simplifying the analysis to an exercise in separating the natural and non-natural parts of the record. Knowing the dates and history of human disturbance would be critical for such an exercise. However, in most cases it is unlikely that gauge data will pre-date human activities in the watershed, and more complex analyses will be required to estimate the natural flow rates. Estimates of the impact of each type of human impact to the river and watershed identified in the natural condition assessment (Chapter 5; Table 5) should be made and tallied to determine the net impact on flow rates.

There are at least three levels of effort that can be applied to estimating natural flow rates on a gauged, human-impacted river:

- Direction of Change. In some cases, it may only be necessary to determine whether the human impact would have decreased or increased flow rates relative to the natural condition. For example, if all the known human impacts would have resulted in depletions of the natural flow rate, and the river still supports the same types of boating as occurred at the time of statehood, then it may be enough to know that the statehood era river would have been even more boatable than it is today. The magnitude of the decrease may be irrelevant to the navigability determination.

- Relative Magnitude of Change. In some cases, it may be enough to know whether the human impacts caused large or small impacts on flow rates. For example, for a river with large ordinary flows, if all of the human impacts were of limited extent (e.g., a single placer mine on a large river), were located in remote portions of the watershed distant from the river channel itself (e.g., the City of Helena, Montana in the Mississippi River watershed), were located near the extreme downstream end of study reach (e.g., dry weather flows from New Orleans into the Mississippi River), or were of the type unlikely to significantly impact the range of ordinary flows (a flood control diversion structure that operates only above the 10-year flood level), then detailed evaluation of the magnitude of such changes would be of little value to a navigability determination.

  Alternatively, the range of human activities may include significant impacts (e.g., diversion of the entire low flow of the Salt River into water storage reservoirs and canals) and less significant impacts (e.g., treated effluent discharge into the Mississippi River) relative to the ordinary range of flow rates. More detailed analysis can be performed for the most significant impacts, or enough of the list of significant known impacts to establish whether the river would have been boatable or not in its natural condition.

- Detailed Quantification. Detailed quantification of losses or gains to the pre-development, natural flow rate of a river require the greatest level of effort, information, and analyses. They are also often the most subject to criticism, differing interpretations, and differing results. In such cases, it can be helpful to step back and evaluate whether the range of opposing estimates creates a meaningful difference in the boatability of the stream (e.g., the types of boats that could be used, the difficulty of boating, the nature of obstacles and obstructions, the duration or reliability of the boating season, etc.), rather than disputing the conclusions of opposing experts. Nevertheless, some situations will require detailed quantification of the various losses and gains to the natural flow rates. In such cases, information relating to each human activity must be quantified. Care should be taken to estimate the change relative to the ordinary range of flow, and to account for seasonal variations in human impacts (e.g., irrigation diversions during the irrigation season; winter water storage and summer releases, etc.). Such efforts may be extremely laborious and have frustrating gaps in the available data. More detail on specific types of detailed quantification efforts is provided in the Special Problems discussion below.

Ungauged River: Natural Condition

For rivers where no stream gauge data are available, information on the range of ordinary flow rates must be derived indirectly, using some combination of the approaches described in the Alternative Sources of Flow Data discussion below. If the river remains in a natural condition, modern observations of the river may be the most useful means of describing the river's natural flow rate, increasing the importance of a thorough field investigation, including boating the river. In addition, the progression of level of detail from Direction of Change to Relative Magnitude of Change to Detailed Quantification described above is also applicable, though Detailed Quantification becomes even more difficult, as well as more useful.

Ungauged Rivers: Altered Hydrology

Quantifying the ordinary and natural hydrology of ungauged, highly impacted rivers is difficult. Some help may be found in the approaches described in the Alternative Sources of Flow Data discussion below, although the inability to field-verify the results is a significant disadvantage and increases the level of uncertainty. In such cases, the importance of the historical record of river conditions and boating accounts is magnified, as is the utility of information collected from similar nearby watercourses. In addition, the progression of level of detail from Direction of Change to Relative Magnitude of Change described above is also applicable, though Detailed Quantification becomes even more difficult, as well as more useful.

Alternative Sources of Flow Data

Flow data are available from a variety of sources. The types and quality of data may vary significantly between sources and should be evaluated for consistency, reliability, and accuracy, and should be reported as such. The following data sources may be useful to supplement standard gauge data or replace it for rivers that lack it:

- Stream Gauges. In addition to the standard US Geological Survey gauge network, a variety of other Federal (BLM, USACE, EPA, FHWA, BUREC, USFWS, NRCS), State (DOT, DWR, GFD, Dam Safety), Local (Flood Control District, DOT, Recharge, Wastewater) and Private (Mines, Boating Groups) entities maintain stream gauging stations or record river flow data. The data available from stream gauges may consist of continuous measurements throughout the year, continuous measurements made seasonally during an open water season, once per day measurements, episodic post-flood maximum flow estimates, written records of flow conditions, or episodic qualitative observations.

- NOAA River Forecast Centers.[45] Information on normal, extreme, and predicted stream flow may be available from the National Oceanic and Atmospheric Administration (NOAA) based on a variety of gauged and observed conditions.
- Field Observations. Quantitative flow measurements are often obtained as part of a navigability field investigation, although qualitative assessment of flow conditions may also be useful (dry, in flood, deep, shallow, rocky, etc.). Field observations made in other (non-navigability) types of scientific and engineering studies are also useful, as described below.
- Historical Descriptions. Descriptions of river flow found in explorer's logs, personal diaries from local pioneers, notes from General Land Office Surveyors, photographs, newspaper accounts, and other historical sources frequently include information about river flows, floods, droughts, and boating accounts that are useful for characterizing natural flow conditions. Historical descriptions may also be useful for identifying changes in flow rates or river conditions due to human impacts.
- Scientific Studies. Studies of aquatic or riparian habitat, fish passage, in-stream flow investigations, water rights cases, water supply, hydropower potential, boating recreation potential, and other investigations may include flow rate estimates or descriptions of the natural variation of river flow. Climate studies documenting historical changes in precipitation, runoff rates, and watershed conditions may also be useful for establishing the normal seasonal and cyclical variation in runoff. Tree-ring studies can also provide estimates of long-term mean flow rates from which to evaluate modern changes in flow.
- Fish Habitat Maps. Environmental studies of existing, potential and/or historical fish habitat may be useful in identifying normal river flow rates and river characteristics. For example, some fish species require deep water and continuous fish passage along the river. Rivers deep enough for some kinds of fish may also be big enough for some types of boating.
- Computer Modeling. In some cases, it may be possible to model runoff rates using watershed and precipitation characteristics, ground water-surface water interactions, or rainfall-runoff relationships. In addition to modeling natural runoff characteristics, computer software may be useful for modeling reservoir and diversion impacts (or removing such impacts) on downstream reaches, or simulating the impact on flow rates of human activities on a watershed or river channel.
- Regional Regression Equations. Regression equations relate known or measurable variables (e.g., watershed area, mean elevation, vegetative cover, etc.) to unknown variables like mean annual discharge, bankfull discharge, flood frequency. Regression equations for such variables have been developed and published for many watersheds by a variety of public agencies and academic researchers. It would also be possible to develop new regression equations relating specifically to navigability characteristics.
- Ordinary High-water Mark. The ordinary high-water mark is a physical feature that can be identified and delineated in the field that indicates the upper limit of the range of ordinary flow, which is useful for distinguishing floods from ordinary flow fluctuations.

[45] https://water.weather.gov/ahps/rfc/rfc.php

- Adjacent Watersheds. In some cases, gauged flow data from a nearby, similar watershed can be adjusted to make estimates of flow conditions in an ungauged watershed, as discussed below.
- Modern Boating Records. Modern boating records can be used to help describe normal season fluctuations in runoff, as most boaters have a preferred type of experience, such as big water (high flow season) or low water (dry season). On ungauged streams, boaters often use a physical mark at a bridge or river access point that indicates when the river stage is sufficient for the type of boating they prefer or when the river is not boatable.
- Historical & Geographical Inference. Some aspects of the historical record can be interpreted to make inferences about normal flow conditions in a river. For example, the fact that the indigenous Hohokam culture developed a highly complex civilization based primarily on irrigated agriculture that lasted for nearly 2,000 years suggests that ordinary flows were reliable enough to irrigate hundreds of thousands of acres of farmland and support a population of more than 200,000 people for a very long time (JE Fuller, 2003). Similarly, the existence of numerous commercial ferries on a river suggests that the river was frequently deep enough to make fording it difficult and worth the expense and inconvenience of using a ferry. Alternatively, inferences about river conditions sometimes can be made from geographical place names, e.g., Hayden's Ferry[46] on the Salt River.

Even where traditional USGS stream gauge data are available, it is useful to consider these alternative sources of flow data to supplement the record and verify the findings of a single data source.

Common Problems with Flow Data

Perfect data sets rarely exist in the real world. In the real world, and sometime one must make do with whatever data are available. Some of the more common problems with flow data for navigability studies include the following:

- Gauge in Wrong Location. If the only stream gauge on the river is located a large distance upstream or downstream of the study reach, the gauge data must be adjusted to account for possible differences in runoff rates. Procedures for making such adjustments within a single watershed, called hydrologic transfer methods are described in (NRCS, 2007; Ries, 2007; Paretti et. al., 2014).
- No Gauge in the Watershed. Procedures for regionalizing gauge data between adjacent watersheds, or for completely ungauged watersheds are described in NRCS (2007), Ries (2007) and on the USGS StreamStats web pages.[47]
- Incomplete Gauge Record. Almost all gauge records have record gaps when the gauging station was out of service or temporarily discontinued. Some gauge records include data from a previous gauge location. Unless the gaps can be filled using data from nearby stations, modeling, other types of observations, or alternative data sources, there may be no choice but to use the incomplete record. In the latter case, it is important to make note of any time gaps and characterize their significance (length of the gap, timing relative to significant historical or hydrological events, etc.), and to evaluate the potential impacts on any conclusions draw from the data.

[46] The original name of Tempe, Arizona.
[47] https://water.usgs.gov/osw/streamstats/

- Short Gauge Record. On some rivers, only a few years of gauge data are available, either because the gauging station is relatively new, or because the station was only operated for a short time. Once again, the short record may be the best available (i.e., only) flow data for the river, necessitating its use. However, it is important to find ways to verify the data, such as comparing with the Alternative Data Sources listed above. It is also important to note the record length when presenting the data.
- Gauge Accuracy. While most gauge operators, such as the USGS, make concerted efforts to collect accurate data, gauging of natural rivers over a wide range of flow rates is subject to varying levels of measurement error. The USGS typically publishes an estimate of their expected accuracy of measure which can range from poor (> ±15%) to excellent (±5%). Once again, such measurements are usually the best available data, and are routinely used in a wide variety of legal and technical applications without further consideration of the measurement error.
- Upstream Diversions. Diversions of flow in or out of a river alter the natural flow rates. Determining the precise magnitude of such diversions is difficult, if not impossible, due to uncertainties in or lack of diversion measurements, poor or lack of record keeping, unavailable records (privacy, etc.), changes in water usage (differing crop cycles, acreages irrigated, improvements in efficiency, weather, population, etc.), structure capacity (changes in design, maintenance, mechanical failures), and many other factors that defy quantification. Some of the possible approaches to quantify the uncertainties in hydrologic data sets are outlined below.
- Upstream Dams. Dams can significantly alter the flow rates measured downstream. Normally, data regarding dam inflows and outflows, as well as water storage levels, are collected by the dam operator and/or downstream water users and are sometimes available to the public. There are numerous computer software packages that can use these data sets to simulate reasonable estimates of what the natural flow rates would have been absent the dam.
- Other Depletions & Additions. Data for some types of depletions and additions to river flow may be gauged and readily available to supplement evaluations of natural river flow. These might include releases from sewage treatment plants, flows diverted for ground water recharge, or near-stream ground water pumping. Other types of depletions and additions, such as dry weather storm water flow, or those caused by grazing, forestation, or urbanization are difficult or impossible to measure directly, and must therefore be estimated.

Some of the common approaches to addressing potential problems caused by using imperfect data sets include the following:

- Worst Case/Conservative Analysis. One way to deal with imperfect data is to evaluate it from a "What's the worst (and best) result possible?" perspective. That is, if any uncertainty or potential error were tilted in favor of the least (and most) desirable outcome, what is the result? If the worst-case analysis concludes that a particular finding occurs, then further refinement of the data may be unnecessary. For example, if there is uncertainty regarding the amount upstream diversions for irrigated agriculture, a worst-case approach might assume that every diversion dam operated at peak efficiency (maximum diversion), and that every farm field was planted with the crop that required the most irrigation (maximum use), with the greatest possible efficiency. Such an approach would result in the maximum rate of flow depletion, which if applied as an adjustment to the long-term gauge records on the disturbed river, would result in the maximum addition of flow to what currently exists. If the river were shown to be not boatable even with this maximum return (addition) of flow, that fact would be highly informative for a navigability determination.

- Relative Impact. Where no quantitative flow data exist from which to compute the magnitude of likely changes from the natural condition, the impact relative to a known adjustment might help determine the magnitude of the impact. For example, consider a river with extensive irrigation diversions from the river, as well as other impacts such as deforestation. If it is known that the level of deforestation was less significant than the irrigation diversions, and the irrigation diversions have been shown by worst-case analyses to have not impacted boating conditions, then it may not be necessary to further evaluate the hydrologic impacts of deforestation.
- Adjustments. It is possible to adjust and correct some data sets by removing obvious outliers, such as correcting for data gaps erroneously recorded as days of zero flow, by extrapolating flow records from working gauges on other parts of the river, or from alternative sources of flow information.
- Verification. Any desktop methodologies should be verified to assure the accuracy and reasonableness of the results. For example, if the results of an analysis of stream gauge data are contradicted by field observations, historical photographs, or other scientific studies, the analysis should be viewed skeptically until any discrepancies between predicted and known conditions can be fully explained or the analysis is corrected.
- Error Bars. Analytical results can be presented with a description of the potential error, such as the standard error of estimate, the 95% confidence limit, or simply the range of results, to better convey the actual level of accuracy.

Finally, it is important to remember that attorneys and their experts will dispute the data and bicker about the conclusions of opposing parties, regardless of the result. Such disputes, unfortunately, are part of the process of a navigability determination and should be expected.

Rating Curves

A rating curve expresses the relationship between flow rate and flow depth, width, or some other hydraulic property of a river section, and is most frequently used to estimate depth from discharge (Figure 38). Construction of rating curves is usually beyond the scope of most ordinary and natural condition assessments, but may be included if the river's physical characteristics are significantly different than the modern condition, and flow depths must be estimated by some form of hydraulic modeling.

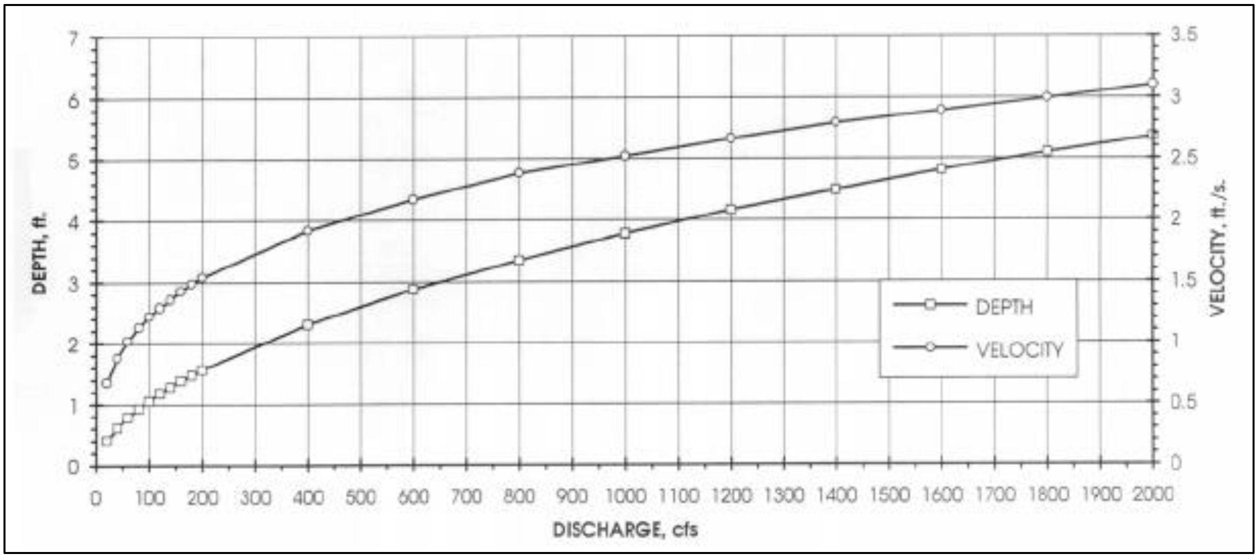

Figure 38. Example of a typical rating curve.

The following considerations should be made when constructing rating curves or using them to draw conclusions about the navigability of a river:

- River Depth. The complexity of trying to quantify the depth of a natural river using a single value was discussed in detail in Chapter 3. On natural rivers, the depth is highly variable at a single cross section, along the length of a river segment, and in time as flow rates change and the river evolves. Therefore, while rating curves are useful, they should be used with caution when attempting to describe the depth and boatability of an entire river segment.
- Maximum vs. Average Depth. As indicated in Figure 7, the average and maximum (boating) depth can vary significantly, depending on the cross-section geometry. It is important to specify whether average or maximum depths are being reported before trying to determine boatability using rating curve results.
- Significance. One of the most useful ways rating curves can be used in navigability determinations is for assessing the impact on boating of historical or hypothetical changes in river, watershed or channel conditions. For example, if studies were performed that concluded that the natural flow rate was 100 cfs higher than modern conditions due to human impacts, the rating curve could be used to estimate the likely change in flow depth, width or velocity caused by a 100 cfs change, and whether the change in depth would be significant relative to boating. For the rating curve shown in Figure 7, a 100 cfs increase in flow would translate to an increase of less than about 0.3 feet, which would be unlikely to significant change what types of boats could be used on the river or significantly extend the boat season for any given boat type.
- Cross Section Type. Cross section data can be obtained by direct survey of the river channel (historical or modern) or from a topographic map. Surveyed cross section data typically better represent the actual cross section geometry because survey points can be taken at every slope break in the section as well as at regularly spaced intervals. Cross section data obtained from a topographic map will only have data points where the cross-section crosses contour lines. Therefore, the topographic map cross section will have less detail and may miss geometric characteristics important to boatability such as the existence of a slightly deeper boating channel or obstacles to boating such as rocks or bars. The differences in accuracy between

surveyed and topographic map cross sections becomes more significant as the contour interval of the mapping increases.

- Verification. Because of the potential for topographic map based rating curves to misrepresent the actual channel depths, it is important to verify rating curve depth estimates using historical data such as river descriptions, photographs, and boating accounts.

Summary

Quantifying the ordinary and natural flow rate is a key component in any navigability study, and is the foundation of any assessment of the boatability of a river segment. In the absence of reliable gauged streamflow measurements, a variety of indirect or alternative data sources may be considered to provide descriptions of the river’s natural flow characteristics. Regardless of the data sources used, it is likely that some judgment and subjective interpretation will be required. Examples of how such judgment was applied in past navigability determinations is provided in the case histories summarized in the following Chapter.

Chapter 9:

Case Histories

Technical issues relating to the ordinary and natural condition of the following rivers raised in the following past title navigability determinations are summarized in this Chapter:

- Case History #1: Salt River, Arizona
- Case History #2: Verde River, Arizona
- Case History #3: Gila River, Arizona
- Case History #4: Mosquito Fork, Alaska
- Case History #5: Knik River, Alaska

Some issues relating to the ordinary and natural condition are common to several of the case histories, but will only be presented once. The case histories are not an exhaustive list of all the issues raised or all the evidence presented regarding the river's ordinary and natural condition, nor is complete documentation for each case provided with this report.[48] Instead, a summary of the issues raised and the types of information provided to address the ordinary and natural condition of each river is presented, with limited discussion of how the matter was evaluated.

The primary objective of providing these case histories is to document the types of issues that may arise during an ordinary and natural condition assessment.

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[48] At the time this report was prepared, documentation and transcripts for the Arizona navigability cases were available at http://www.ansac.az.gov/ .

Case History #1: Salt River, Arizona

Status: The navigability of the Salt River has been under consideration since the 1980's. In 1987, the Arizona Legislature passed House Bill 2017 which attempted to relinquish State interest in streambed lands under the Salt, Verde and Gila Rivers, and allowed affected landowners to obtain a quit claim deed to any sovereign lands for a nominal fee. The law was declared unconstitutional by the Arizona Court of Appeals (Arizona Center for Law in the Public Interest v. Hassell, 1992). Thereafter, the Arizona Legislature passed House Bill 2594 in 1992, which established the Arizona Navigable Stream Adjudication Commission (ANSAC) which was authorized to make navigability determinations based on particularized information submitted by any interested party. Since that time, ANSAC has found the Salt River to be non-navigable three times. After ANSAC's first two decisions, their rulings were remanded by the Arizona Court of Appeals (Defenders of Wildlife v. Hull, 2001; Winkelman v. ANSAC, 2010). At the time this report was prepared in 2018, ANSAC had once again determined that the Salt River was non-navigable, although ANSAC's final ruling had not yet been published. It is likely that ANSAC's most recent non-navigability decision for the Salt River will once again enter another phase of court review and appeals in the future.

As noted in the main body of this report, the 2010 Winkelman v. ANSAC decision included specific language regarding the need to consider the Salt River in its ordinary and natural condition, and offered some broad outlines as to what constituted ordinary and natural. Therefore, the 2016 evidentiary hearings before ANSAC included considerable discussion about the navigability characteristics of the Salt River's ordinary and natural condition. Although there were some commonalities regarding the ordinary and natural condition of the entire river, some of the issues raised affected only certain river segments. For the purposes of this case history, the issues related to the Salt River's ordinary and natural condition may be considered in four sections,[49] as follows:

- Salt River below Granite Reef Dam ("the lower Salt River")
- Salt River between Stewart Mountain Dam and Granite Reef Dam
- Salt River from Stewart Mountain Dam to the upstream end of Roosevelt Lake
- Salt River above Roosevelt Lake

Geographic features that demark the reach boundaries are shown in Figure 39.

[49] In the most recent hearings before ANSAC, the Salt River was divided into six segments which are slightly different than the river sections discussed above. The "Salt River above Roosevelt Lake" section combines Segments 1-3 from the ANSAC hearings, as the ordinary and natural condition issues were the same for these three segments. Note that the State made no claim of navigability for Segment 1 (above Apache Falls).

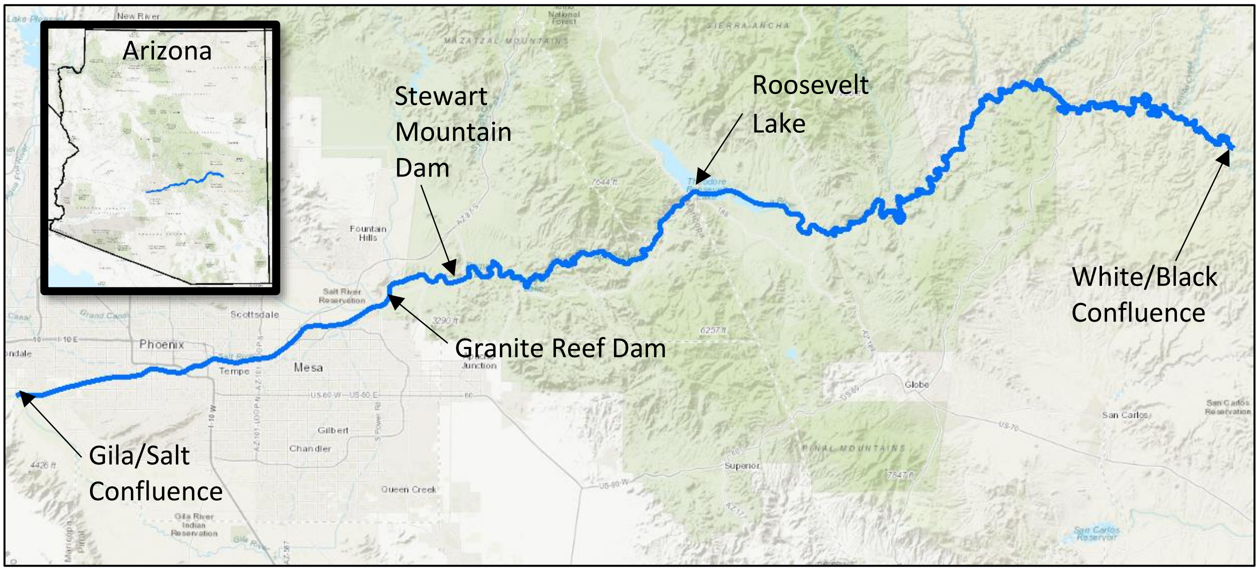


Figure 39. Salt River reach location map.

<u>Salt River below Granite Reef Dam ("the lower Salt River")</u>

The lower Salt River is the most highly impacted river segment in Arizona. A combination of six major water supply dams and a major irrigation diversion system have completely dried up the river, except during rare floods that exceed both the reservoir storage and irrigation diversion capacity. In addition, the river has been heavily mined for sand and gravel, channelized for flood and erosion control, and realigned and encroached to accommodate urbanization of metropolitan Phoenix. The modern Salt River is also affected by excessive ground water pumping, a declining water table, urban dry weather flows, and effluent releases. Irrigation diversions were (re)built as soon as the Phoenix area was settled in the 1860's, eventually including twelve major canals that could completely drain the river for much of the year well before Statehood in 1912. Roosevelt Dam, the largest of the water supply dams, was completed in 1910 and reduced most Salt River flows to only those required to meet the water rights of downstream users.

The primary discussion points regarding the ordinary and natural condition of the lower Salt River included the following:

(1) Ordinary vs. Natural Conditions. In the early iterations of the lower Salt River navigability case, non-navigability proponents argued that since the diversions and dams existed prior to Statehood, the depleted river conditions should be considered ordinary and used as the basis of the navigability determination. They also argued that the presence of Hohokam irrigation dams along the segment for nearly 2,000 years also supported the theory that irrigation dams were part of the river's ordinary condition. This theory was rejected by the Arizona Court of Appeals because dams are not part of a river's natural condition, regardless of how ordinary they might have become during periods of human settlement.

(2) Flow Depletion/Reconstruction of Pre-Development Flow. Because irrigation diversions were built almost as soon as the river valley was settled, there were no systematic streamflow

measurements within the river segment when it was still in its natural condition. The only available[50] long-term gauge records were for stations located upstream of the modern reservoirs, leaving nearly 1,300 mi^2 of ungauged contributing watersheds between the gauges and the lower Salt River. Points of contention regarding the natural flow rate included the relative contributions from the ungauged watersheds downstream of the gauges, the contributions to streamflow from, or losses to, the declining water table, and other possible losses of streamflow. In the end, lacking any alternatives, long-term records from the upstream gauges were used to demonstrate the normal seasonal fluctuations in flow, and as a minimum estimate of flow rates in the disturbed river segment. In addition, estimates of the mean and median annual flow rate were based on a US Geological Survey modeling study prepared independent of the navigability hearings (Thomsen and Porcello, 1991). Ultimately, the differences in flow rates estimates from either side did not result in substantive differences in estimated flow depths or reconstructed boating conditions.

(3) Representative Flow Rate. Much of the argument about the ordinary and natural condition hydrology of the lower Salt River centered on what flow rate should be used in the navigability assessment. All sides correctly noted that in flood-dominated streams, the mean discharge can be significantly higher than the median discharge. Thus, estimates based solely on mean discharge may overestimate the occurrence of boatable conditions. There was also some obfuscation about the differences in mean annual, mean of annual, annual means, and means based on daily measurements or annual flow volumes (and medians), though once again, the differences were more academic than practical when the estimates were translated to rating curve depths. Finally, the significant variation in flow rates between the late winter-spring high flow period and the summer low flow period was also an issue, as boating conditions during the high flow period were measurably better than during summer low flows. Use of mean or median annual data overestimated ordinary flow rates during the dry season, but underestimated ordinary flow rates during the wet season.

(4) Erratic Flow. The non-navigability proponents cited historical descriptions of the river as being erratic and subject to major floods as evidence that the river could not be regularly boated or that the occurrence of boatable flows was unpredictable. The navigability proponents argued that the historical descriptions of an "erratic" river were made by irrigators, not boaters, and probably referred to more calendar dependent irrigation requirements, where below normal flow had greater consequences than they did for boating. The navigability proponents also used flow duration curves to point out that while the range of ordinary flows may be wider than what is common for many humid region rivers, the full range of ordinary flow rates on the Salt River would support many types of boating. Finally, navigability proponents used upstream gauge data to document that floods, while large, occurred far less than one percent of the time, and were not part of the ordinary condition of flow.

[50] The water utility company that controls the irrigation diversions on the lower Salt River, as well as the upstream water supply dams, was a party to the navigability case and did not release any of its flow diversion, dam release, or other flow measurement records.

(5) Channel Movement. During large floods, the low-flow channel in natural lower Salt River could move hundreds or even thousands of feet within its floodplain. During such floods, the low flow channel is engulfed by flood flow and the "banks" may be substantially widened. Non-navigability proponents argued that such massive channel movement and channel widening precluded post-flood boating and would have made construction of navigation infrastructure (docks, harbors, etc.) impractical. Proponents of navigability argued that the low flow channel geometry is naturally reestablished shortly after or during the receding limb of a flood and that the location of the channel within the floodplain makes little difference to whether the low-flow channel itself is boatable. They also pointed out the persistence of ferry locations during the historical periods as evidence that not all infrastructure would be adversely impacted by channel movement. Further, the navigability proponents pointed out the other rivers subject to flood and seasonal channel changes have been found navigable (e.g., See Case History #5).

(6) Channel Pattern. Non-navigability experts characterized the lower Salt River as having a naturally braided channel, and opined that braided channels are not navigable, or are at least more difficult to boat. Navigability proponents pointed out that other braided rivers have been found navigable, and that the lower Salt River had a compound channel pattern, not a braided pattern.

(7) Rating Curves. Because of the massive human-caused changes in the modern lower Salt River, recent field observations were of little use for reconstructing ordinary and natural condition flow depths and channel characteristics. Therefore, both sides relied in part on rating curves constructed from circa-1904 (pre-statehood) topographic maps (5-ft contour interval). Differences between rating curve depth estimates were not significant, so the legal debate focused on the following issues: (1) Cross section location – was the chosen cross section site representative of the entire segment?, (2) Manning's N value – too high or low?, (3) Channel slope – was the rating curve slope representative of pools or riffles, (4) Accuracy of the topographic mapping - was use of 5-foot mapping appropriate for estimating depths of 1-2 feet, and did it realistically depict the natural hydraulic geometry of the low flow channel, (5) Whether the average (lower depth) or maximum (higher depth) values should be used, and (6) The relevance of "limiting" depths in riffles to the overall segment characteristics. Despite the differing opinions about the methodology, the resulting depth estimates were not significantly different relative to boatability of specific boat types.

(8) Obstacles & Obstructions. Non-navigability proponents argued that the lower Salt River had numerous types of obstructions that limited or precluded navigability, including irrigation dams, rapids, riffles, split channels, braiding, and beaver dams. Navigability proponents countered that irrigation dams were not part of the natural condition of the river, that any rapids or riffles would have been rated as Class I at most (based on comparison with adjacent river segments, the geologic setting, and historical boating accounts), and therefore would not be an obstruction to low draft boating, that the river's low flow channel was not braided and that the few channel splits could be boated, and that beaver dams would be unlikely to span the several hundred foot wide low flow channel on a flood-dominated river, particularly given the scarcity of woody vegetation along this desert river. Furthermore, none of the historical accounts of boating the

segment mention problems associated with braiding, channel splits, or beaver dams, and only one mentions encountering a riffle.

(9) Verification. The disagreements over the rating curve results and the existence of boating - obstructions highlighted the need for verification of desktop methodologies and other theories about past river conditions. Navigability proponents attempted to verify their results by considering information collected during other phases of the navigability study, such as historical ground photographs, stream gauge measurements, and channel descriptions in GLO survey notes. The following example illustrates how rating curve depth estimates (from both sides) were found to underestimate actual flow depths.

A photograph of the Hayden ferryboat from January 15, 1901 (Figure 40) found in a local historical archive provided a means of verifying some of the flow depth estimates. Two USGS stream gauges existed near the upstream end of the lower Salt River segment on that date, and recorded that the inflow to the segment was at least 504 cfs, not counting any reduction due to diversion at any of the more than five irrigation dams located between the gauges and the ferry, or any losses to infiltration into the streambed. Rating curves based on topographic mapping and computer models indicated the maximum depth at 500 cfs would be about one to two feet deep, and about 250 feet wide, hardly deep and wide enough to warrant use of a ferry, and significantly different than what is shown in the historical photograph in Figure 40.

Figure 40. Photo of Hayden's Ferry from January 15, 1901. From Arizona State University Special Collections.

<u>Salt River between Stewart Mountain Dam and Granite Reef Dam</u>

Stewart Mountain Dam is the fourth and furthest downstream of the four major water supply dams on the Salt River. In the current condition, the four upstream dams have the capacity to store all the normal river flow and most of the flood flows from the Salt River. Normally, flow is released from the dams from late spring to early fall to meet the water supply needs of the Phoenix metropolitan area. For most of the fall, winter, and spring, less than 10 cfs is released, just enough to meet minimum environmental needs in the reach between Stewart Mountain Dam and Granite Reef Dam. At Granite Reef Dam, the entire river is diverted into a canal system except during usually large floods that exceed both the reservoir storage and diversion capacity of the Salt-Verde system.

There were two unique discussion points regarding the ordinary and natural condition of the Salt River between Stewart Mountain Dam and Granite Reef Dam:

(1) Changed Seasonality of Flow. The natural annual hydrograph for the Salt River peaks in spring in response to snowmelt from the upper watershed, with a secondary peak during the late summer monsoon (Figure 41). In the natural condition, periods of low flow normally occurred in mid-summer, late fall and winter. After completion of the system of dams on the Salt River, the high flow season was altered so that it now occurs from spring to early fall. The disturbed condition high flow season also lasted about twice as long as the natural spring runoff season. The disturbed condition low flow season had much lower flows than the natural low flow season. Finally, the median daily discharge increased compared to the natural condition.

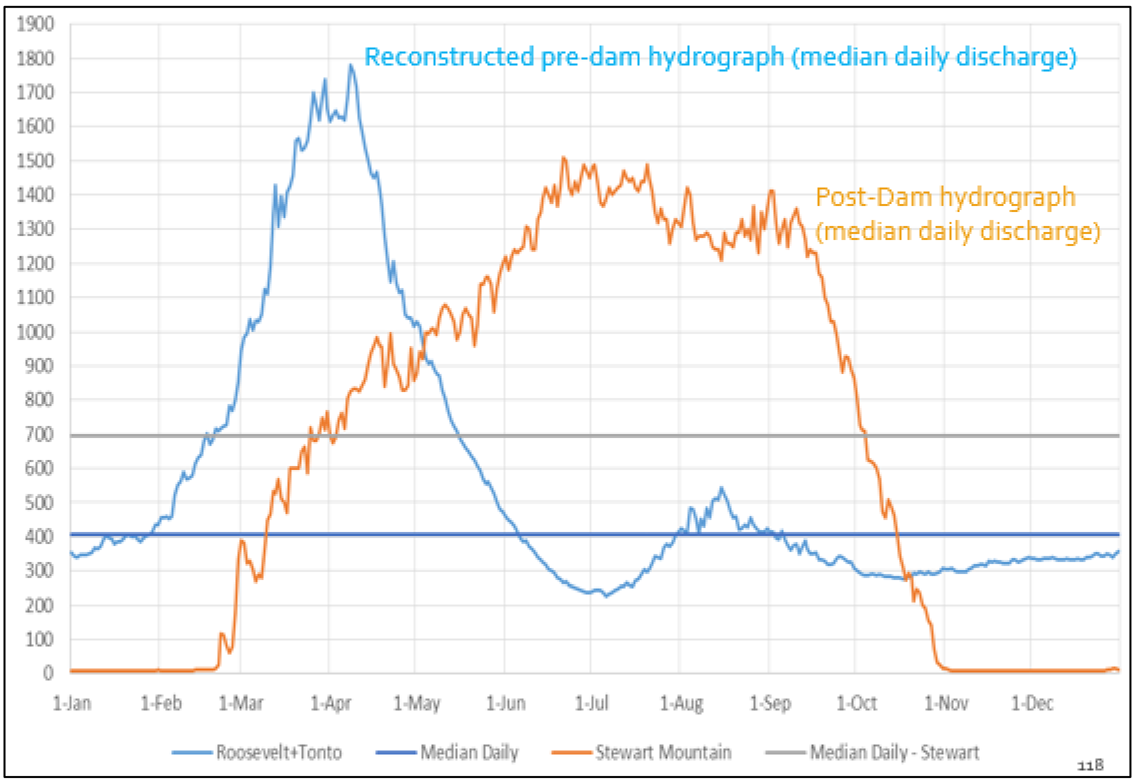


Figure 41. Natural and altered flow hydrographs for the Salt River below Stewart Mountain Dam.

There was no disagreement over the facts regarding the change in flow seasonality, as it was very clearly documented by USGS flow records, as shown in Figure 41. Any disagreement focused on the impacts of the seasonal change on the navigability of the reach. The opponents of navigability argued that the modern flow regime improved boating conditions by extending the high flow season by several months, by making discharges more regular and predictable (uniform release rates, few flood releases), and by changing the high flow season to summer when boating the weather was more pleasant for boating. Proponents of navigability argued that improved modern boating conditions does not mean that the pre-dam, natural flow conditions were *un*boatable, and pointed to accounts of historical boating as evidence.

(2) Geomorphic Response to Dams. Opponents of navigability argued that the upstream dams significantly changed the physical characteristics of the Salt River downstream due to changes in flow seasonality, loss of channel-shaping flood peaks, release of sediment-deprived water, and an increase of invasive vegetative species such as tamarix on the channel banks and in the floodplain. The navigability opponents held that the river has experienced long-term scour which made the river deeper (i.e., more boatable), increased bank vegetation (due to invasives and decreased flooding) which made the river narrower and more stable (i.e., deeper and more boatable), reduced the channel slope (i.e., increased depth), decreased the amount of braiding, reduced the proportion of sandy bed material and increased bed armoring, and changed the channel position between the time of dam closure and the present.[51] These arguments were based primarily on the classic response of alluvial channels downstream of dams described in the scientific literature, rather than pre- and post-dam (or modern) channel measurements in the Salt River itself. The objective of these arguments was to demonstrate that the river had changed from its natural condition to the degree that extensive evidence of modern boating[52] or observations of existing river conditions in this segment were not relevant to a navigability determination based on the ordinary and natural condition as of the time of statehood.

The proponents of navigability presented pre-dam (1904) and modern detailed topographic maps of the Salt River (Figure 32) and aerial photography (Figure 42) showing that the historical and modern river channel was depicted with similar widths, channel pattern, and channel position, with some exceptions that were well within the range of ordinary, natural river behavior over a 108 year period. No reach-wide pre-dam depth measurements were available from which to compare modern flow depths, but the types of boats and recorded boating experiences in the historical accounts were found to be consistent with modern boating and field conditions. Also, the types of historical boats used on the river have similar depth and width requirements to the types of boats that normally boat the river today. They also noted that the topographic channel profiles submitted by the opposing experts showed no long-term scour downstream of Stewart Mountain Dam, which was consistent with the lack of field evidence of long-term scour or channel instability (Table 4) in the reach. In addition, they noted that while the upstream dams in fact reduce the amount of flooding, they do not eliminate flooding, and provided historical matching photographs showing that channel vegetation is still removed and the channel can be eroded by post-dam floods (Figure 43). Finally, the navigability proponents provided evidence that explained why the river did not exhibit the textbook response to an upstream dam (shallow bedrock, coarse bed material, carbonite-cemented bank material, well-vegetated channel banks, infrequency of channel-forming flows, resilience of pool-riffle streams).

[51] In this case, the navigability opponents asserted that braiding and channel movement is evidence of non-navigability, contrary to many past navigability findings. It was not clear how loss of sandy bed material was relevant since sand bed channels are typically easier to boat than cobble-bedded rivers.
[52] Including boating the river in an exact replica of the wooden boat used by the Kolb Brothers trip through Grand Canyon in 1911 (See cover photo).

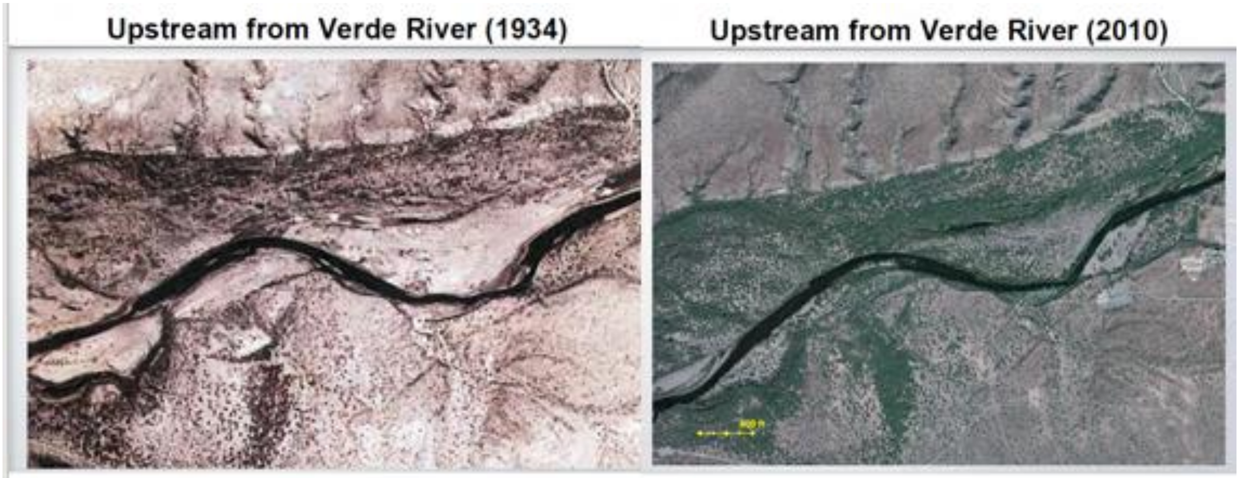


Figure 42. Comparison of historical and modern aerial photographs of the Salt River downstream of Stewart Mountain Dam.

Figure 43. Matching photographs from September 1938 (2,390 cfs) and March 1979 (13 cfs). Source: Webb et. al., 2007

<u>Salt River from Stewart Mountain Dam to the upstream end of Roosevelt Lake</u>

Between Stewart Mountain Dam and the upstream end of Roosevelt Lake, the Salt River now lies under four reservoirs that completely obscure the pre-dam channel (Figure 45), making direct observation of the natural river characteristics impossible. The principal challenge for the ordinary and natural assessment for this river segment was the paucity of records that pre-date the reservoirs, from which the physical characteristics of the natural condition could be determined. The few available records consisted of a small number of ground photographs taken before or during construction at some of the dam sites, a few historical accounts from early historians and explorers who visited the area, several accounts of boating trips that pre-date dam construction, local topographic mapping near one dam (Stewart Mountain), and two USGS 15-minute topographic maps from the early 1900’s (Figure 44).

The available data sources were used to reconstruct the ordinary and natural condition of the river under the reservoirs in the following ways:

(1) Flow records. Depletions from upstream diversions and other human impacts were estimated as described above. In this segment, the depletions were relatively minor during periods of low flow, with less significant impacts at median or high flow rates. In general, the flow depletions made only small differences in estimates of flow depth and width, and would have only minimal

impacts on the types of boats that could have been used, the level of difficulty of boating the river, or the duration of the boating season for any given boat type.

(2) Topographic Maps. Pre-reservoir USGS topographic maps (Figure 44) were available for the entire segment from which the following basic information about the natural river could be gleaned:
   a. Downstream of the Roosevelt Dam site, the river was located at the bottom of a deep, narrow bedrock canyon. Upstream of the Roosevelt Dam site, the river was located in a broad alluvial valley. Analogies to these basic channel types can be found in undisturbed river reaches upstream of Roosevelt Lake from which estimates of likely channel conditions could be made.
   b. There are no rapids or waterfalls called out along the Salt River on maps. However, rapids are also not called out in other less disturbed reaches of the Salt River canyon where rapids are known to exist.
   c. There are no tightly spaced contours crossing the river that might indicate large rapids, waterfalls, or steep-sloped river segments, even where detailed topographic mapping was available at proposed dam sites.
   d. There are few major tributaries that join the river that might be locations for tributary confluence rapids. The largest tributaries join the river at small flats so that the confluences are set back well away from the low flow channel. Most of the coarse sediment would have been deposited in these flats rather than in the low flow channel, and would be unlikely to form rapids on the main channel of the Salt River.
   e. The longitudinal channel profile for the Salt River indicates that the reach under the reservoirs is slightly flatter than the river upstream of Roosevelt Lake, but steeper than the river downstream of Stewart Mountain Dam. Inferences regarding channel conditions, obstacles, and pattern can be made by analogy to less disturbed upstream and downstream river segments.

(3) Analogy to Less Disturbed Salt River Segments. A common method of identifying the pre-disturbance (natural) condition of a river to find undisturbed reaches on other parts of the river that have similar geology, physiography, watershed area, vegetation, and hydrology characteristics. Then, conditions in the disturbed reach can be inferred and extrapolated from the less disturbed reaches. For this reach, geologic maps were compared to determine what units crop out along the now-submerged portion of the River relative to less disturbed river segments upstream and downstream. The geologic units at named rapids upstream to similar units and lithologies in the submerged reach were catalogued to estimate the likelihood of similar rapids in the submerged reach. Similarly, the characteristics (size, approach angle, slope, geology) of rapids at tributary mouths in natural upstream reaches were compared to the characteristics of tributaries in the submerged reaches to estimate the likelihood of tributary mouth rapids.

(4) Historical Accounts. Several of the historical accounts of boating and exploration included river descriptions that could be used to infer channel depths, widths, and obstacles. In particular, the boating accounts described the presence of some rapids near the Roosevelt Dam site, but relatively easy boating conditions in the lower portion of the now-submerged reach.

(5) Ground Photographs. Historical photographs (Figure 45), primarily taken at the dam construction sites, provided evidence of the channel pattern, presence of small rapids, and river width at those locations.

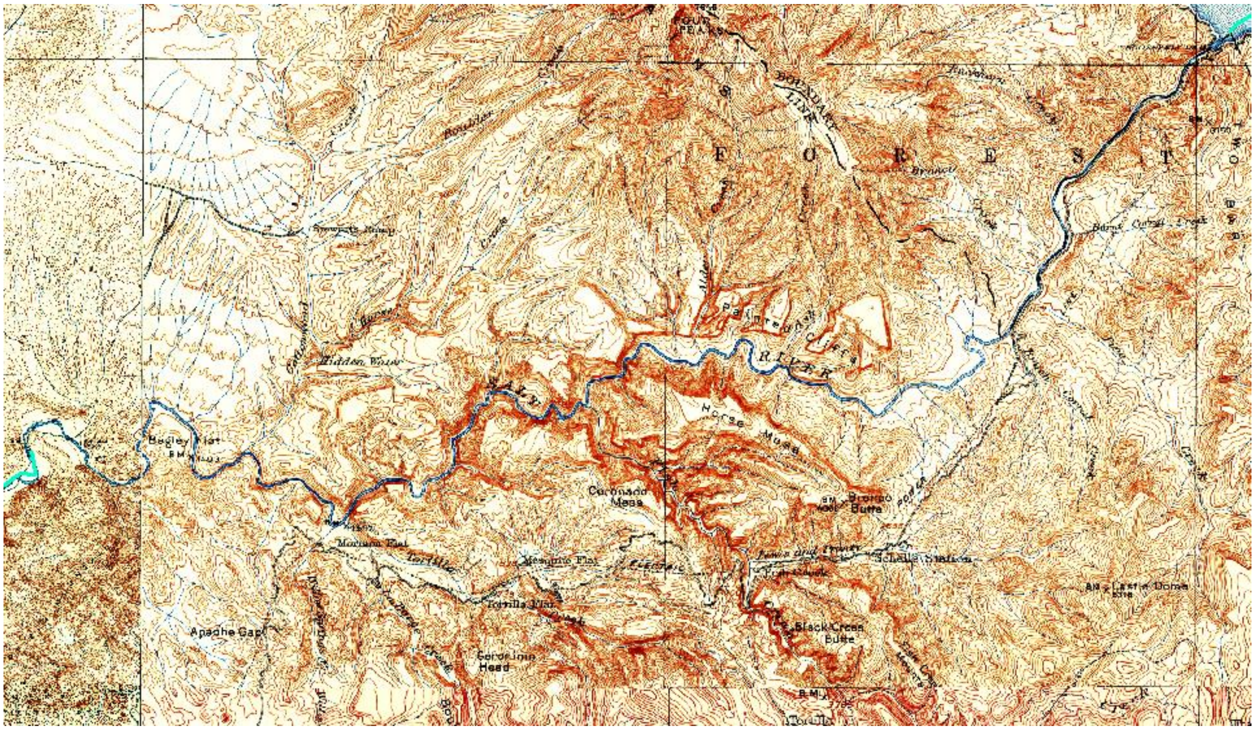


Figure 44. 1904-1907 USGS topographic maps of the Salt River now located under four reservoirs.

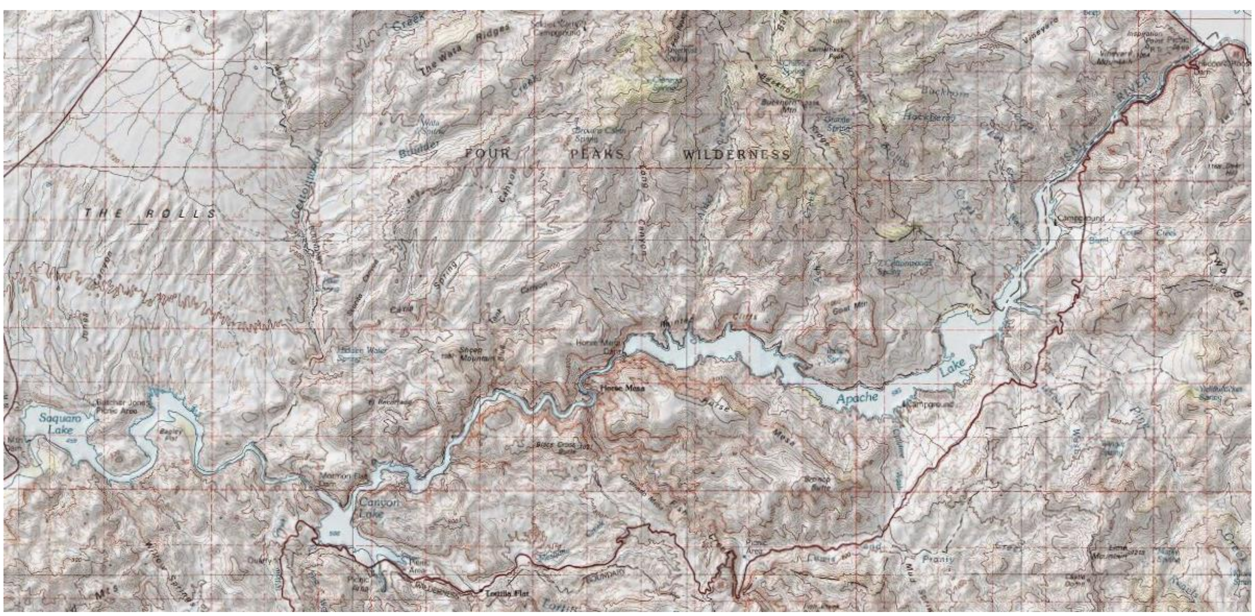


Figure 45. 2011 USGS topographic map showing the modern Salt River.

Figure 46. Salt River near the (pre-) Roosevelt Dam site, 1908 (Source: Phoenix Public Library).

<u>Salt River above Roosevelt Lake</u>

Above Roosevelt Lake, almost all the Salt River is located in a confined, bedrock canyon, and most its watershed lies within managed National Forest or undeveloped tribal lands. Despite the relative lack of human impacts compared to the Salt River downstream of Roosevelt Lake, there were some historical upstream diversions (an interbasin transfer, limited irrigation) and consumptive uses for small towns and scattered ranches, as well as logging and grazing that altered the natural condition of the watershed to some degree. Arguments regarding the ordinary and natural condition of the Salt River above Roosevelt Lake centered on the following three issues:[53]

(1) Flow Depletions. Estimates of the diversion and depletion rates were made using the same techniques described above for other segments of the Salt River. All parties agreed that natural flow rates in the Salt River above Roosevelt Lake were slightly higher than existing conditions, and there were no significant disagreements about the estimated depletion rates. The changes in flow depth computed on rating curves due to addition of the depletion rate to the flow rates estimated from the long-term USGS gauges was only a few tenths of a foot,[54] which is not enough to change the types of boats that could be used in the river segment or significantly

[53] There was also considerable discussion about the rapids that existed in the ordinary and natural condition in the upper portion of this reach. However, these arguments focused on whether the presence of rapids precludes navigability, not whether the rapids existed in the ordinary and natural condition.
[54] Natural, undepleted flow depths would have been slightly higher, making the river marginally better for boating (deeper flow, slightly longer boating season).

change the level of difficulty. In general, it was agreed that the natural flow would have consisted of somewhat higher low flows, with minimal impacts on flow rates during spring high flow periods.

(2) Physical Condition of the River. Because the upper Salt River lies within a bedrock-bounded canyon and is nearly untouched by any direct impacts on the river channel, it was generally agreed that the river channel was substantively within its ordinary and natural condition, with one exception at Quartzite Falls.

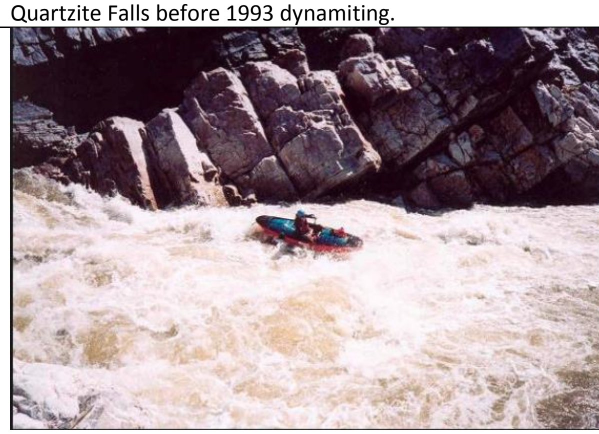
(3) Quartzite Falls. The upper Salt River supports a seasonal commercial recreational boating industry during the spring runoff period, and is also a popular river for private river trips. In 1993, some boating enthusiasts dynamited the Quartzite Falls Rapid, changing it from a Class IV-V rapid to a Class III-IV, making it easier to boat and eliminating the short portage used by some modern boaters who wished to avoid running the rapid (Figure 46). Prior to 1993, at some times of the year, delays waiting for groups to scout and run, or to portage, the rapid could last for several hours on some days. After the rapid was dynamited, delays at the rapid were less common. The segment has three other Class IV rapids, as well as a number of Class II and III rapids, and is a well-known and popular whitewater boating destination during its short season. Opponents of navigability argued that the river had been altered from its natural physical condition, making evidence of modern commercial recreation irrelevant to navigability.[55] Proponents of navigability argued that modern commercial recreation existed both before and after the one rapid was dynamited, that change from a Class V to a Class IV (or IV to III) rapid did not make a substantive difference to either the types of boats used or the level of difficulty.

[55] Navigability opponents also argued that modern commercial recreational boating was not evidence of navigability in general for a variety of other reasons.

Quartzite Falls before 1993 dynamiting.

Quartzite Falls before 1993 dynamiting.

Quartzite Falls at less than 200 cfs in August 2016.



Quartzite Falls at highwater.

Figure 47. Photographs of Quartzite Falls Rapid in the Salt River canyon.

Case History #2: Verde River, Arizona

Status. The navigability status of the Verde River has been tied to the same extended legal process described above for the Salt River. At the time this report was prepared in 2018, ANSAC had once again determined that all segments of the Verde River were non-navigable, and the case was currently entering another phase of court review and appeals.

Ordinary & Natural Condition. The Verde River has many of the same issues regarding its ordinary and natural condition described for the Salt River above, but several unique ones as well. The discussion below focuses on issues unique to the Verde River. For the purposes of this report, issues relating to the following reaches of the Verde are presented:

- Upper Verde River – Granite Creek to Sycamore Creek[56]
- Verde Valley – Sycamore Creek to Beasley Flat

Geographic features associated with the two Verde River reaches are shown in Figure 48.

Upper Verde River – Granite Creek to Sycamore Creek above Clarkdale

The upper Verde River above Sycamore Canyon is substantively in its ordinary and natural physical condition, with two minor exceptions near active ranches (Verde Ranch and Perkinsville Ranches) where farming, diversions and grazing have altered stream conditions for short reaches of less than one mile each. The remainder of the upper Verde is located within an unpopulated narrow bedrock canyon within the Prescott National Forest and remains relatively undisturbed.

There was some suggestion by the non-navigability proponents that prior to over-harvesting by trappers in the early to mid-1800's and Anglo-American settlement in the region, there were more beaver dams on the upper Verde than exist today. They asserted that the presence of beaver dams made the river non-navigable because of the extra effort required to pull a boat over or around numerous beaver dams. However, there was no physical evidence that conclusively demonstrated the number, type, or specifics regarding beaver dams in the past compared to existing conditions, or whether their presence improved (deeper water), degraded (increased difficulty), or had no effect (same number of dams, or beaver trappers in small boats would not be deterred by beaver dams) on boating conditions.

All parties agreed that the ordinary and natural flow rates in the upper Verde have been depleted by irrigation diversions and groundwater pumping. However, the estimates of the magnitude of flow depletion made by opposing experts varied by more than 20 percent. The differences in the reconstructed flow rates were primarily due to assumptions made about the total irrigated acreage, the type(s) of crops irrigation and their water demands, how return flows were estimated, and how ground water withdrawal impacted surface flow rates. Flow reconstructions were also hindered by gaps in stream gauge records, and the lack of detailed records kept by irrigators, farmers, and ground water pumpers.

[56] Sycamore Creek above Clarkdale. There are three other tributaries named Sycamore Creek that join the Verde River downstream of Clarkdale.

Ultimately, although the estimates of depleted flow varied significantly, the differences spoke more to the difficulty of boating the upper Verde caused by shallower flow depths or the duration of the boating season, rather than whether it could be boated at all or what types of boating it would support.

Figure 48. Verde River navigability study reach location map.

Verde Valley – Clarkdale to Beasley Flat

Flow depletions from irrigation withdrawals and ground water pumping significantly altered the ordinary and natural condition of the Verde Valley section of the Verde River. There are approximately twenty historical and/or active diversion dams between Sycamore Creek and Beasley Flat, several of which can completely dewater the river at certain times of year. Estimates of the magnitude of flow depletion were affected by the same types of uncertainties, data gaps, and assumptions described for the upper Verde River.

A more contentious issue regarding the ordinary and natural condition of the Verde Valley involved anecdotal evidence of significant channel change thought to have occurred in the 1890's. Some published recollections of early pioneers suggest that the river in the Verde Valley underwent a significant morphological transformation in the 1890's, from a wide, marshy floodplain that lacked a defined channel to the narrower, deeper, more defined channel seen today. The descendants of some early pioneers recollected family stories of being able to jump across the main channel of the Verde or walking across it without getting one's ankles wet. Some of the old-timers believed that the change in channel conditions was caused by a combination of over-grazing, draining of malarial swamp land, hunting beaver to near extinction, and a large flood in 1891.

The non-navigability proponents relied on these anecdotal accounts to assert that the river was no longer in its ordinary and natural condition. Therefore, any evidence from modern recreational boating or modern observations of the channel were irrelevant to the navigability determination. Furthermore, because the changes in channel condition occurred prior to statehood, none of the post-1891 historical boating accounts were relevant either. Finally, they argued that change was due to human disturbance of the river corridor, rather than natural river processes. Therefore, they asserted that the non-navigable condition of marshy floodplains with no defined channel should be considered the ordinary and natural condition of the river.

Navigability proponents pointed out some of the problems with the anecdotal evidence. For instance, the few available photographs of the river that pre-date the 1891 flood show a river channel that is very similar to the river conditions today. No photographs that support the anecdotal accounts were available. Also, the testimony of an Apache Tribal elder (submitted by a non-navigability proponent) included the fact that the Apache name for the river translated as "big, wide river," and that the river used to be bigger and wider than it is today, which is inconsistent with the pioneer's anecdotal recollections. Similarly, pre-1891 General Land Office surveys recorded a well-defined river channel rather than the channel-less marshland described by the descendants of pioneer families. Finally, whether the Verde Valley was actually over-grazed and whether there was a linkage between grazing and channel change that could not be explained by the 1891 flood alone has not been established by any scientific analysis.

Case History #3: Gila River, Arizona

Status. The navigability status of the Gila River has been tied to the same extended legal process described above for the Salt River. At the time this report was prepared in 2018, ANSAC had once again determined that all segments of the Gila River were non-navigable, and the case was currently entering another phase of court review and appeals.

Ordinary & Natural Condition. The Gila River has many of the same issues as described for the Salt and Verde Rivers above, but several unique ones as well. The discussion below focuses on issues relating to the ordinary and natural condition of the Gila River that have not already been reviewed in the other case histories. For the purposes of this report, issues relating to the ordinary and natural condition of the following reaches of the Gila River are presented:

- Gila River – Downstream of Safford
- Gila River – San Carlos Canyon

Gila River – Downstream of Safford

Downstream of Safford, Arizona (Figure 49), the Gila River flows out of the bedrock canyons of the Gila Box and into the wide alluvial Safford Valley. Within the Safford Valley, the Gila River has a compound channel pattern consisting of a sinuous low flow channel inset within a wide active floodplain and an even wider geologic floodplain. The flood regime of the Gila River is similar to other dryland rivers in that the largest floods may be three or more orders of magnitude larger than the dry season base flow. Such floods can significantly alter the morphology of the entire active floodplain as well as the position of the low flow channel within the floodplain. D.E. Burkham's (1972) classic study of channel change in response to floods was performed on this reach of the Gila River, using information obtained from historical diaries, journals, and photographs, General Land Office (GLO) survey maps, USGS and other topographic maps, and aerial photographs. Burkham documented a cycle of massive erosion, widening, and straightening of the river during large floods, followed by narrowing and increased sinuosity during the intervening periods between floods (Figure 50).

Figure 49. Location map for the Gila River downstream of Safford, Arizona.

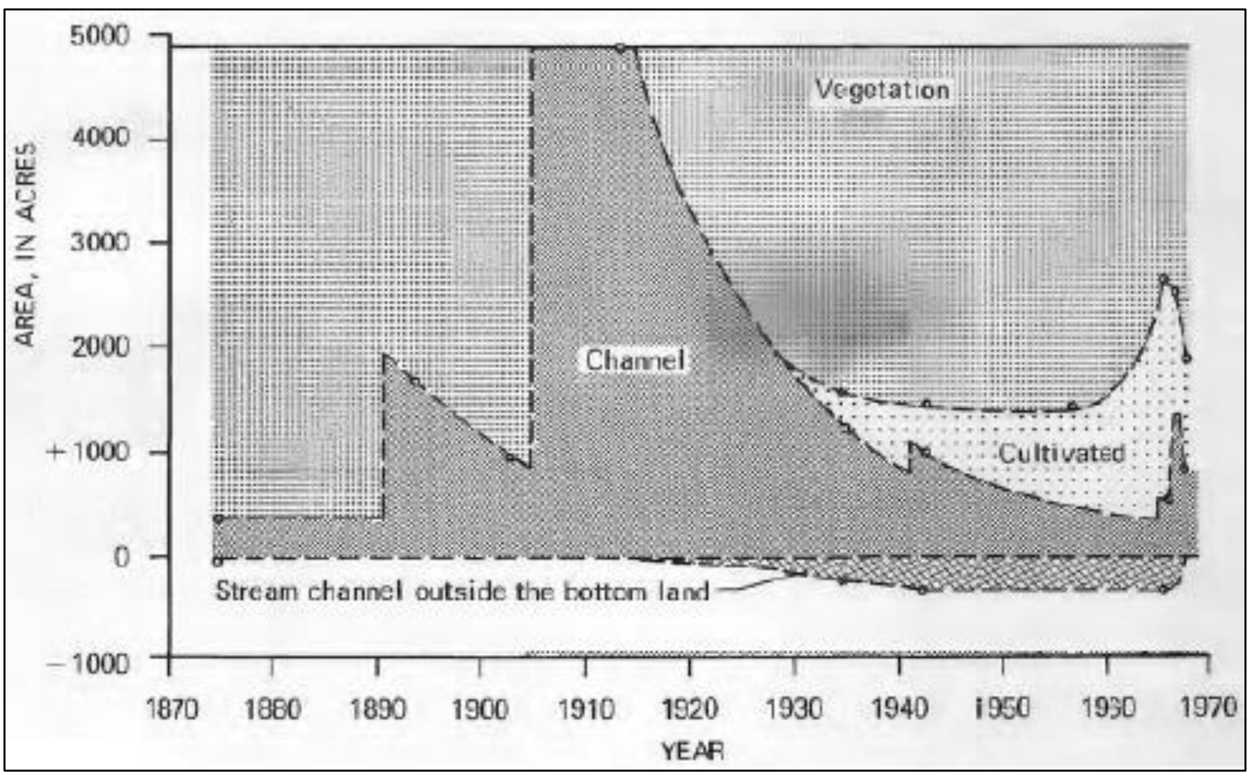


Figure 50. Historical changes in bottomland conditions on the Gila River, 1846-1970 (Burkham, 1972).

Burkham's work led to the following issues regarding the ordinary and natural condition of the river relative to navigability:

(1) Channel Definition. Burkham described the flood impacts in terms of their effect on the "channel." Several experts relied on Burkham's work in documenting the natural condition of channel, particularly its width,[57] at various times in the history of the Gila River. However, Burkham's definition of "channel" was for the active channel, as defined in this report, not the boating or low flow channel. The width changes he described were more related to changes in the ordinary high-water marks, not the banks of low flow channel, as illustrated by the presence of a flowing and much narrower, post-flood low flow channel within Burkham's (active) channel (Figure 51).[58] Because of this misinterpretation of channel definitions, estimates of flow depth and other characteristics for the boating channel based on the (incorrect) active channel width were inaccurate. This misunderstanding demonstrates the need to consider scientific studies in the proper context before applying them to a navigability determination.[59]

Figure 51. Figure 4(a) from Burkham (1972) showing a May 1909 photograph of the narrower, sinuous low flow channel within the flood-widened active channel. Burkham calls the "channel" the area devoid of vegetation.

(2) "Ordinary" on Flood-Dominated Dryland River. Burkham's work leaves no doubt that the largest floods on the Gila River can cause significant changes within the entire floodplain, some of which persist for decades (Figure 50). During these major floods, bank vegetation can be eroded from the channel banks, the low flow channel can move by hundreds of feet within the active floodplain, there can be changes in sinuosity, and major changes in the character of the floodplain. Based on these findings, there was some discussion in the navigability hearings that the Gila River was ordinarily in a state of disequilibrium, either being altered by floods or slowly recovering from such alterations.

While the state of equilibrium on a flood-dominated, dryland river has different characteristics than many humid region rivers that experience largely passive floods, it is important to

[57] Note that Figure 50 shows changes in total channel acreage, not width.
[58] Burkham specifically notes that low flow channels develop "during the floods" (p. G13). These low-flow channels were not the focus of his study.
[59] It is also worth noting that one of the objectives of Burkham's study was to identify the role of human impacts such as grazing, invasion of non-native tamarix, and agriculture, calling into question the relevance of his findings to the natural condition of the river. Also, other investigators (Olmstead, 1919; Klawon, 2004) found that Burkham's model of cyclical channel change was not supported in other segments of the Gila River, and that extreme floods in the mid-1800's did not widen the active channel.

distinguish between flood impacts to the floodplain which persist for long periods in dryland rivers versus the response of the boating channel, which Burkham described as re-forming "during the floods." The re-establishment of the low-flow channel during the receding limb or soon after a large flood is well documented by examination of post-flood aerial photographs and field visits to the modern river after floods. Given the fine-grained alluvial substrate and lack of bank vegetation following a large flood, it is understandable how low flows would rapidly reform a low flow channel, albeit in a different location within the floodplain.

Nevertheless, the question of what "ordinary" means on a flood-dominated, dryland river is a valid one, and is a question that probably must be answered by a court. From a scientific perspective, it may be enough to state that ordinary may mean something different in the arid west than in the Pacific Northwest or on rivers in other climatic zones. Therefore, it is important that a regionally appropriate definition of "ordinary" be used in navigability determinations. Whatever the court determines, their decision should be based on the characteristics of the boating channel rather than the broader ordinarily dry floodplain, should be based on the natural condition of the river, and should use the definition of "ordinary" provided in Chapters 6 and 7 of this report.

(3) Ordinary Condition at Statehood. Between 1905 and 1917, the Gila River experienced a cluster of extreme floods that dramatically changed the overall character of the river (Figure 50). Arizona became a state in February 1912, during this period of extreme flooding. Therefore, the argument was raised that because the floods were natural events, the flood-altered condition of the river should be considered its ordinary and natural condition, and the navigability determination be made based on the river conditions at that time. Further, it was argued that any accounts of boating the river, or modern observations of the river's characteristics, made before or after this period should be discounted because they did not occur on the river when it was in the flood-modified condition that existed at statehood.

Again, this argument is one that must be decided by a court. From a scientific perspective, it would be important to sort out how much of the channel change during the period of extreme flooding around the time of statehood affected the boating channel, as opposed to the overall floodplain. It would also be important to examine the flood history of the river, perhaps extended by use of tree-ring records and paleoflood studies, to determine how unusual (i.e., non-ordinary) this period of flooding was, and whether the impacts on the boating channel from the cluster of floods could be considered ordinary or unusual. This would require documenting the channel responses to a range of past floods.

<u>Gila River – San Carlos Canyon</u>

Downstream of Coolidge Dam, the Gila River enters a narrow bedrock canyon river segment for the next 20 miles (Figure 52). The low flow channel occupies most of the canyon bottom in this segment, and in some reaches the open water extends from canyon wall to canyon wall. In locations where there is a floodplain, the main channel banks are well vegetated with dense riparian vegetation, including many large trees. In some places, bank erosion and time have caused some of the trees to lean or fall into the boating channel. These fallen and leaning trees can create occasional strainers and sweepers. During low flows, the strainers are minor obstacles and a nuisance, which are easily to navigate through or around. During higher flows, the strainers become a more significant hazard that require careful piloting to avoid.

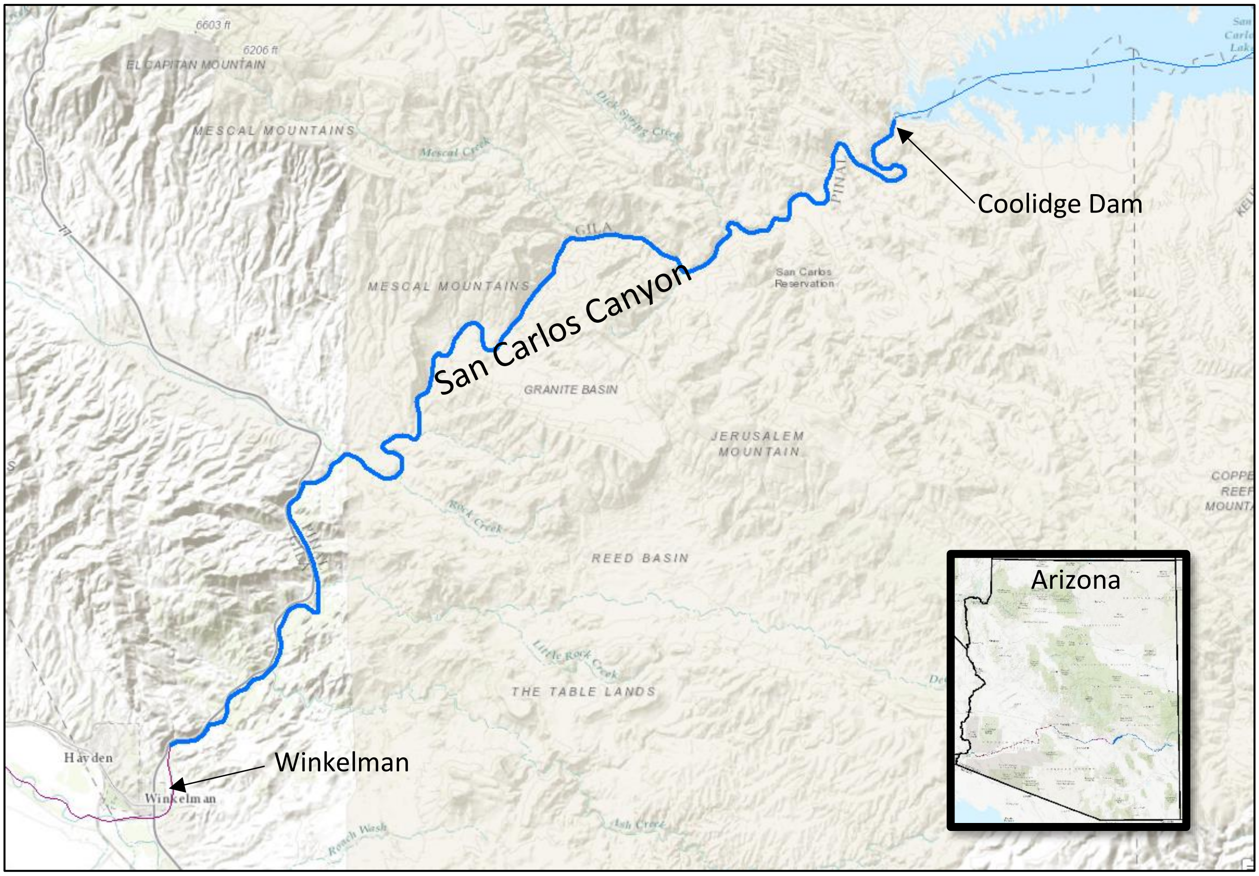


Figure 52. Location map for the San Carlos Canyon reach of the Gila River, Arizona.

There are several ordinary and natural issues associated with the strainers in this segment of the Gila River:

(1) Obstacles vs. Flow Rate. For some natural characteristics of a river, whether they are an obstacle or an obstruction is at least partially a function of the flow rate. Some features are easy to navigate at low flow and difficult at high flow, such as the strainers in the Gila River San Carlos Canyon (Figure 53). Other features are more difficult to boat at low flow, such as rapids that become washed out at higher flows. Therefore, when classifying features as obstacles or obstructions, it is important to consider their characteristics during the range of ordinary flow rates, and note any variation that might occur at different flow levels.

(2) Impact of Upstream Dams. The condition of the San Carlos Canyon Segment of the Gila River is an example of how upstream flood control can negatively affect the boatability of a river. Although Coolidge Dam's main function is not for flood control, because its reservoir is frequently well below its maximum capacity, it provides a flood control function and does not release runoff during most seasonal high flows or floods. Without the occurrence of channel-clearing floods, vegetation can expand into the channel and trees that fall into the main channel

are not pushed downstream. Over time, the non-natural increase in strainers could have an impact on the difficulty of boating the segment. Therefore, it is important to document the full range of possible impacts of upstream dams, including indirect impacts caused by a lack of floods.

Figure 53. Strainers and sweepers in San Carlos Canyon Segment of the Gila River, February 2014 (220 cfs).

As a side note, the evaluation of this reach provided an important lesson in the importance of field work, rather than simply relying on published records. The early work on this segment of the Gila River noted the paucity of modern and historical boating accounts, and quoted descriptions of the trials and tribulations of the few who did boat it. One such historical document included a quotation from the circa 1853 Bartlett Boundary Survey that the canyon was impassible. However, more detailed later work identified that the reach was sometimes boated recreationally in canoes, kayaks, and small rafts. It was also discovered that one of the reasons for the lack of modern boating was the limited or difficult access to the reach due to the lack of roads and presence of tribal lands. The State's project team was able to obtain access to the reach, took the opportunity to canoe and kayak it in February 2014 at a flow of about 220 cfs. In contrast to past accounts, the team found the river to be quite easy to boat, with no significant challenges, and no rapids above a Class II rating (and very few of those). There were in fact many sweepers and strainers due to the lack of channel-cleaning floods downstream of the dam since 1993. This trip inspired further research into Bartlett's description of the canyon as impassible, only to find out that he was referring to its use as a wagon or canal route, not as a boating channel. Thus, the field investigation provided valuable insights to the river condition that would not have been otherwise discovered.

Case History #4: Mosquito Fork, Alaska

Status: In 2012, the State of Alaska filed a claim of ownership of the bed of the Mosquito Fork, a tributary to the Fortymile River system in the upper Yukon area in Alaska, near the town of Chicken (Figure 54). Shortly before going to trial in 2015, the U.S. Attorney, acting on behalf of the U.S. Bureau of Land Management (BLM), vacated the federal government's claim to the river, in effect acknowledging that the Mosquito Fork is a navigable river.

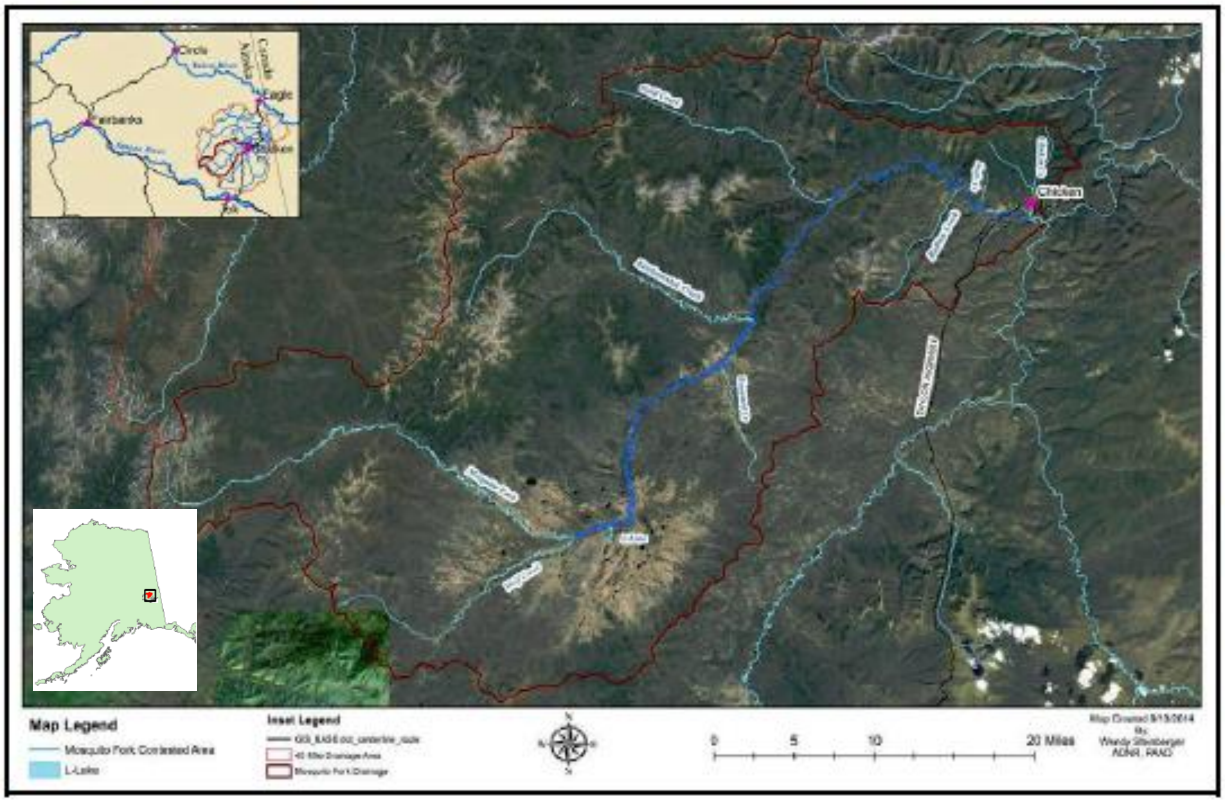


Figure 54. Location map for the Mosquito Fork, Alaska.

Ordinary & Natural Condition. The watershed of the Mosquito Fork is only minimally touched by civilization. The watershed is in a nearly pristine condition, except for the small town of Chicken, the remains of an abandoned indigenous village to which there are no roads, a few abandoned hunting cabins, and the Taylor Highway bridge near Chicken. There are, however, a number of mining claims in and along the lower parts of the river, and the river has a history of small-scale river bed mining that dates back more than 100 years. Because of these potential disturbances of the natural river, the State performed an evaluation of the river's ordinary and natural condition.

The initial reconnaissance indicated that the watershed and river channel appeared to be in a natural condition, and that humans had only minimal impacts on the watershed (Figure 55). The historical analysis identified the river's mining history, noting the changes in mining techniques in its early to history to those used more recently after the advent of modern environmental regulation. A field reconnaissance was conducted by helicopter and by inflatable raft. The field investigation did not identify any of the standard field signs of channel disturbance, and no substantive differences between the channel in the mined and unmined reaches were identified. In addition, no differences in channel width, pattern, or bank conditions were identified from comparisons of historical and recent aerial photographs. The conclusion of the ordinary and natural condition analysis included the following:

1. Existing mining activities do not alter the navigability characteristics of the river.
2. The most significant mining activity occurred below the Chicken Creek confluence (Figure 56), in a reach that the BLM had already determined to be navigable.
3. The river had substantively recovered from whatever disturbance in the boating conditions of the river may have been caused by past in-stream mining.
4. The river was currently in a natural condition with respect to navigability.

After review and evaluation by the BLM experts, the U.S. Attorney stipulated to the State's position regarding the river's ordinary and natural condition, concluding that the river had recovered or remained in a natural condition relative to its navigability characteristics despite historical and on-going in-stream mining.

Figure 55. Photographs of the Mosquito Fork. Clockwise from upper left: (1) meandering river channel in upper reaches, (2) historic abandoned mining dredge near West Dennison Fork confluence, (3) inflatable rafts on gravel bar and channel bend, (4) active overbank mining operation in lower reach near Chicken, AK.


Figure 56. Abandoned historic mining dredge on the Mosquito Fork near Chicken Creek and the Dennison West Fork confluences.

Case History #5: Knik River, Alaska

Status: In 2015, the State of Alaska initiated work to claim portions of the Knik River from its source at the pro-glacial lake at the toe of the Knik Glacier downstream to where the river enters Township 16 North, Range 3 East, Seward Meridian, Alaska (Figure 57). In September 2017, the federal government filed a Quiet Title Disclaimer with the US District Court, Alaska, acknowledging that the entire Knik River downstream of pro-glacial lake was navigable.

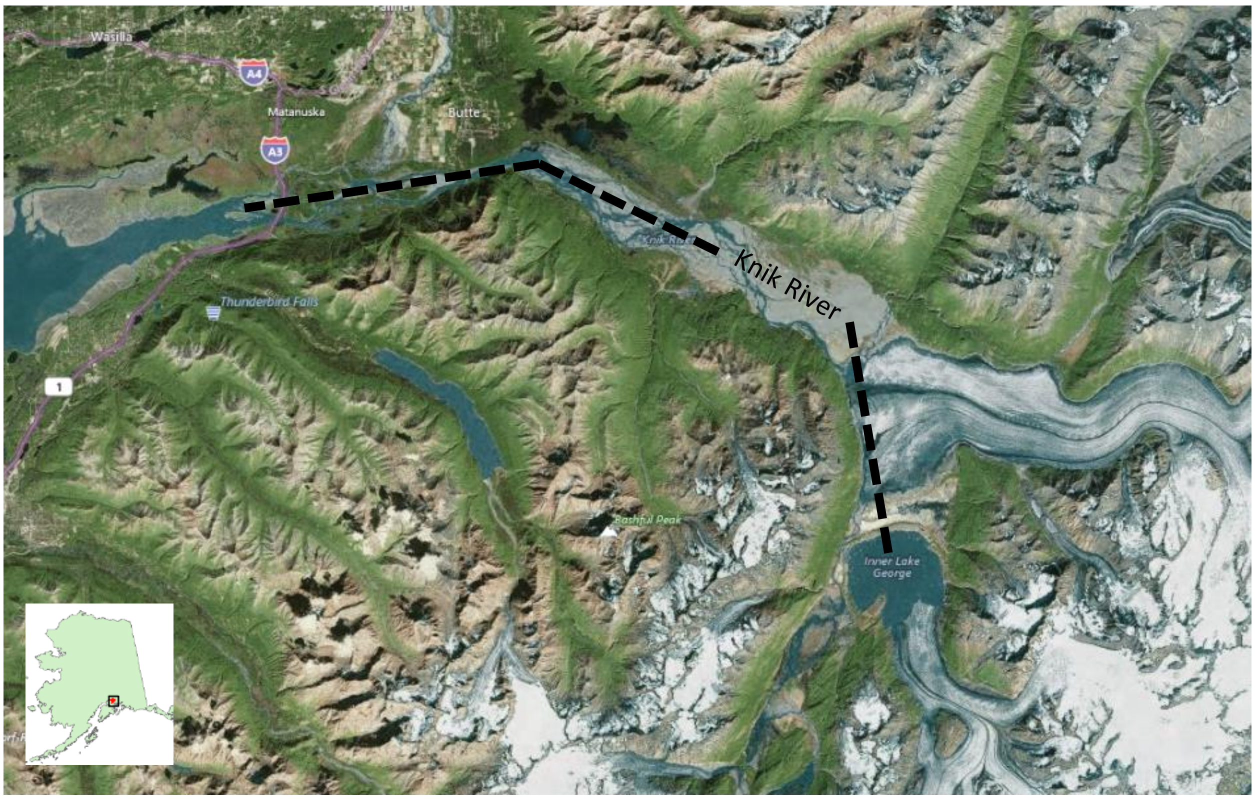


Figure 57. Knik River Location Map.

Ordinary & Natural Condition. Much of the Knik River watershed is extensively glaciated, rugged mountain terrain with nearly no development of any kind and very few direct human impacts (Figure 58). The primary source of runoff into the highly braided river is snowmelt and glacial melt water, outflow from the glacial Lake George,[60] and direct runoff from seasonal precipitation. The river is frozen for a large portion of the year. The Knik River is tidally influenced at its outlet at the Knik Arm of the Cook Inlet. Prior to Alaskan statehood in 1959, and up until 1966, the Knik River was known for its extreme floods caused by glacial outbursts (Figure 60). These large floods were initiated when sufficient water was impounded behind a natural dam formed by the Knik Glacier to float and/or breach the glacier and catastrophically release the stored water to the river downstream. These floods would occur annually, and last for six to ten days (Figure 59, Figure 61). The floods would overwhelm the river channel and floodplain, rewriting the morphology of the river, and causing massive changes in channel

[60] Historically, there were three distinct lakes forming “Lake George” at the upper end of the Knik River.

location within the geologic floodplain. Glacial outburst floods have not occurred on the Knik River since 1966[61] due to glacial retreat and regional thinning of glaciers due to climatic warming and other factors.

The Knik River case raised the following issues regarding the ordinary and natural condition of the river:

- Winter Season Freeze. Like many rivers in Alaska, the Knik River is frozen in winter, which may last for more than half of the year, and which makes boating on (liquid) water impossible. The lack of year-round boatable conditions is not unique to the Knik River or to Alaska, and has been thoroughly addressed by various courts as not precluding navigability.
- Short Boating Season. The boating season is relatively short, generally in the five months between May and September, between time of ice breakup and the winter freeze. The existence of a naturally and ordinarily short boating season is not unique to the Knik River and has been thoroughly addressed by various courts as not precluding navigability.
- Wide Range of Ordinary Flow Rates. Within the open water season on the Knik River, there is considerable variation in the ordinary range of flow, even without considering the extreme flood discharges of the annual glacial outburst flood (Figure 62, Figure 63). Mean monthly discharges in the open water season range from about 2,000 to 25,000 cfs, a range equivalent to a full order of magnitude (Figure 59). However, this wide range in ordinary flow rates did not prevent the opposing parties from concluding that the river was navigable.
- Glacial Outburst Floods. Peak discharges on gauged outburst floods between 1948 and 1966 ranged from 144,000 cfs (1966) to 359,000 cfs (1959). These peaks are more than an order of magnitude larger than the long-term median discharge rate of 14,300 cfs.[62] Furthermore, the variation in discharge during outburst floods on any given calendar day varied over three orders of magnitude during the open-water season (Figure 61). However, the existence of such extreme floods did not prevent the opposing parties from concluding that the river was navigable, even though the timing of the floods was not completely predictable and occurred at different times during the open-water season (Figure 61).
- Flood-Related Channel Change. Because of the magnitude and highly erodible condition of the geologic floodplain of the Knik River, the glacial outburst floods could cause massive changes in the locations of the boating channel, the number of braids, and the flow depths and widths at any given point along the river. Even after cessation of the glacial outburst floods in 1966, the Knik River continues to experience rapid changes in channel position and the location of the boating channels within the various braids of the river system during the open-water season. However, despite the long history of rapid, continual, and episodic channel change, the natural condition of ordinary and non-ordinary flood-related channel change did not prevent the opposing parties from concluding that the river was navigable.
- Cessation of Glacial Damming of Lake George. The end of glacial outburst floods significantly changed the ordinary condition of both annual peak floods and their impacts on channel morphology. As shown in Figure 62, the flow duration curve for the Knik River changed

[61] Glacial outburst floods occurred annually until 1966, except for 1963, but have not occurred since 1966. The period of regular outburst floods included the date of Alaska statehood in 1959.

[62] The median discharge for outburst flood years was 9,400 cfs, and 14,800 cfs for non-outburst years, making the outburst floods two orders of magnitude larger than the median flow in outburst years. The outburst years median is less than the non-outburst year median because of the volume released in a short time period in the outburst flood itself.

significantly, particularly for flows below the median discharge. However, despite a change in the ordinary hydrologic condition of the river, both parties concluded that the changes did not preclude a finding of navigability.

- Braiding River Conditions. The Knik River is highly braided, which is typical for glacial outwash rivers. The river also carries very high sediment loads that result in formation of sand bars, dunes and other bedforms that migrate and move continually. Boating the middle reaches of the river requires the ability to distinguish boatable and non-boatable channels, and use of boats with shallow drafts to prevent grounding. However, the issue of the braided channel pattern and natural braided channel processes was not raised as evidence of non-navigability by either party.
- Human-Induced Climate Change. The existence of human-caused climatic warming is well established in the scientific community, as well as its impact on accelerating the retreat of glaciers throughout the world. For the Knik Glacier, climate-related glacial retreat apparently crossed a threshold after 1966, after which the glacier no longer formed dams which could impound runoff in a manner that led to glacial outburst floods. However, the issue of human influences on climate change was not raised as an issue related to the natural condition of the river, probably because the river was boatable both before and after the end of the glacial outburst floods.

In summary, the Knik River was found navigable despite changes in the ordinary hydrologic condition of the river that may have been at least partially related to human impacts, and despite an ordinary and natural condition that included extraordinary floods and a wide range of ordinary conditions.

Figure 58. Photographs of the Knik River. Clockwise from upper left: (1) looking upstream along braided river channels toward Knik Glacier, (2) looking downstream over braided flood channels toward Knik Arm, (3) Knik Glacier calving into lower Lake George, (4) Knik Glacier and icebergs at lower Lake George.

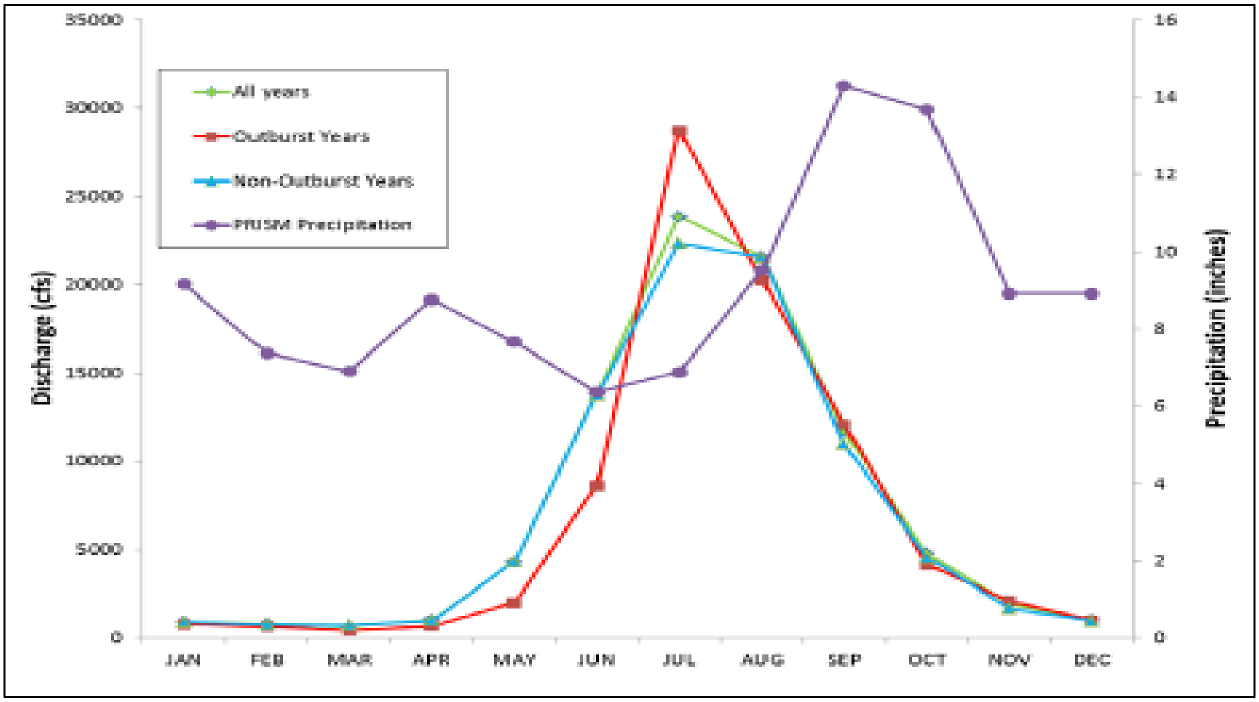


Figure 59. Mean Monthly Discharge and Precipitation for the Knik River (Alaska Hydrologic Survey, 2016).

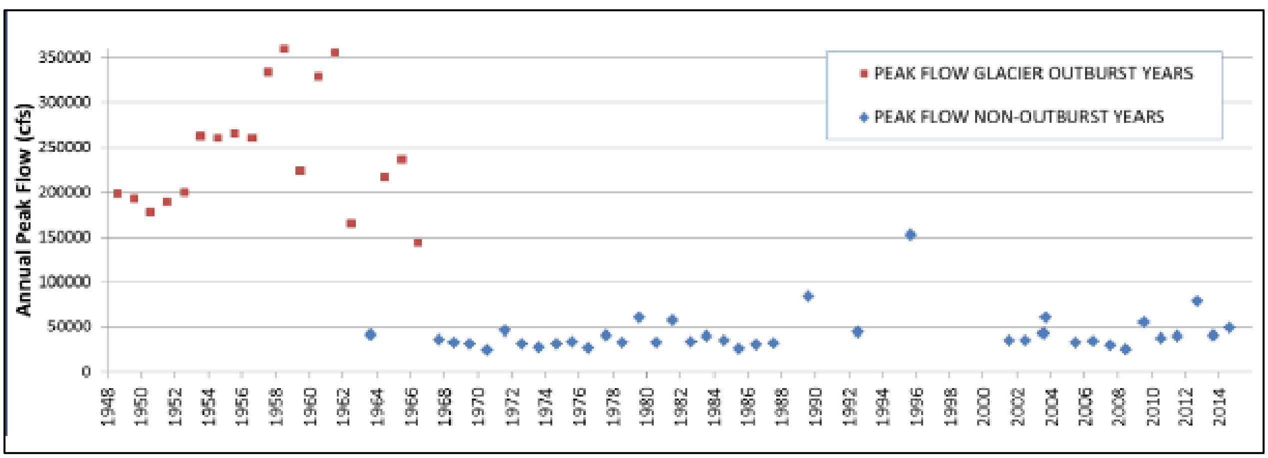


Figure 60. Annual peak discharge for the Knik River, 1948-2014, showing reduction of annual peaks after 1966 (Alaska Hydrologic Survey, 2016).

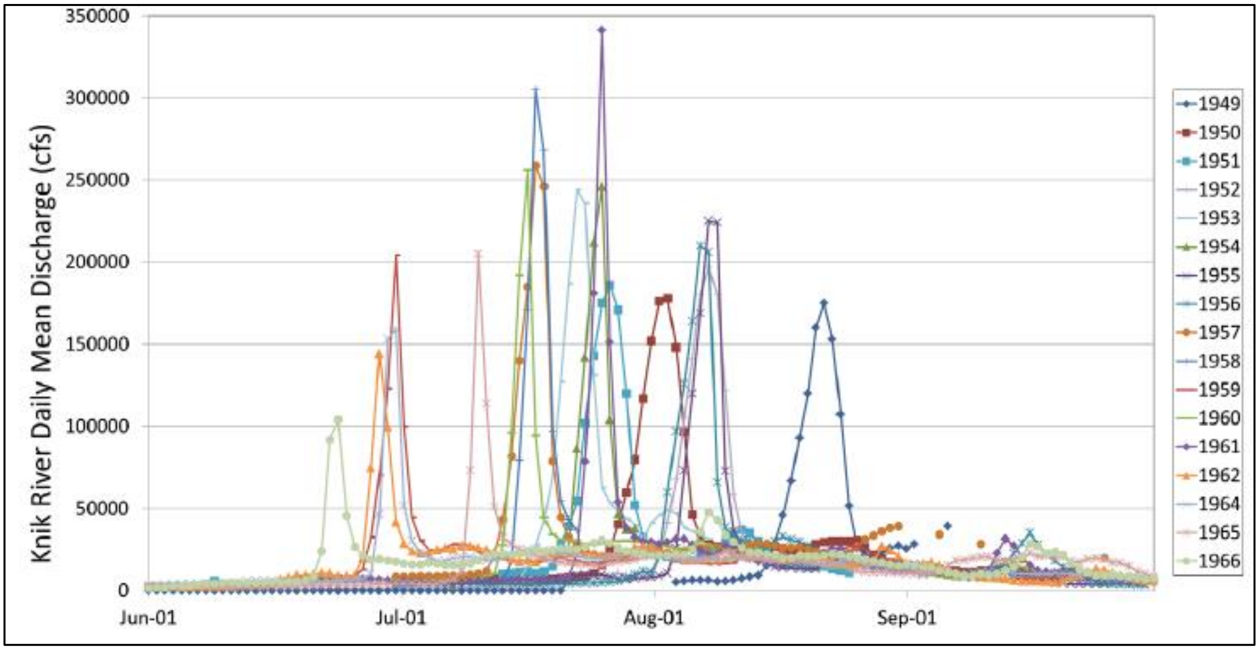


Figure 61. Mean daily discharge during outburst flood periods, 1949-1966 (Alaska Hydrologic Survey, 2016).

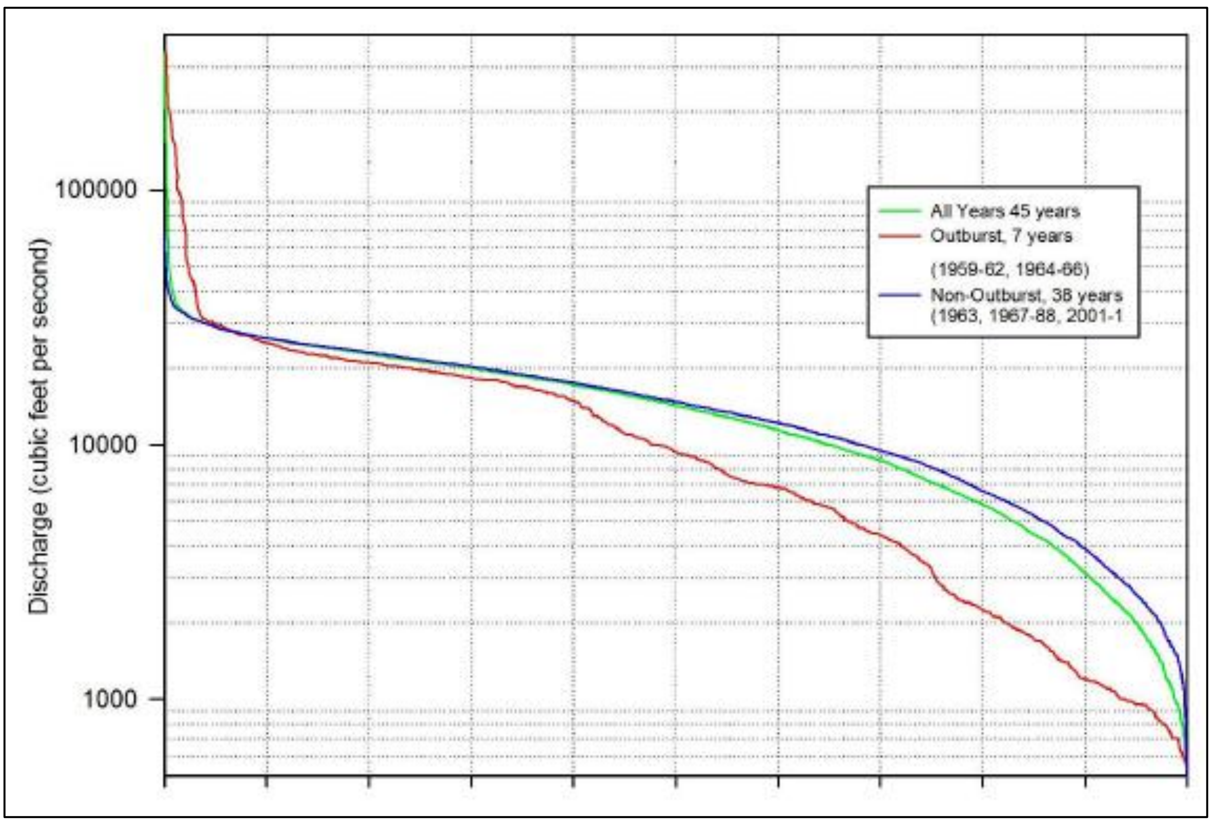


Figure 62. Impact of glacial outburst floods on the flow duration curve (Alaska Hydrologic Survey, 2016).

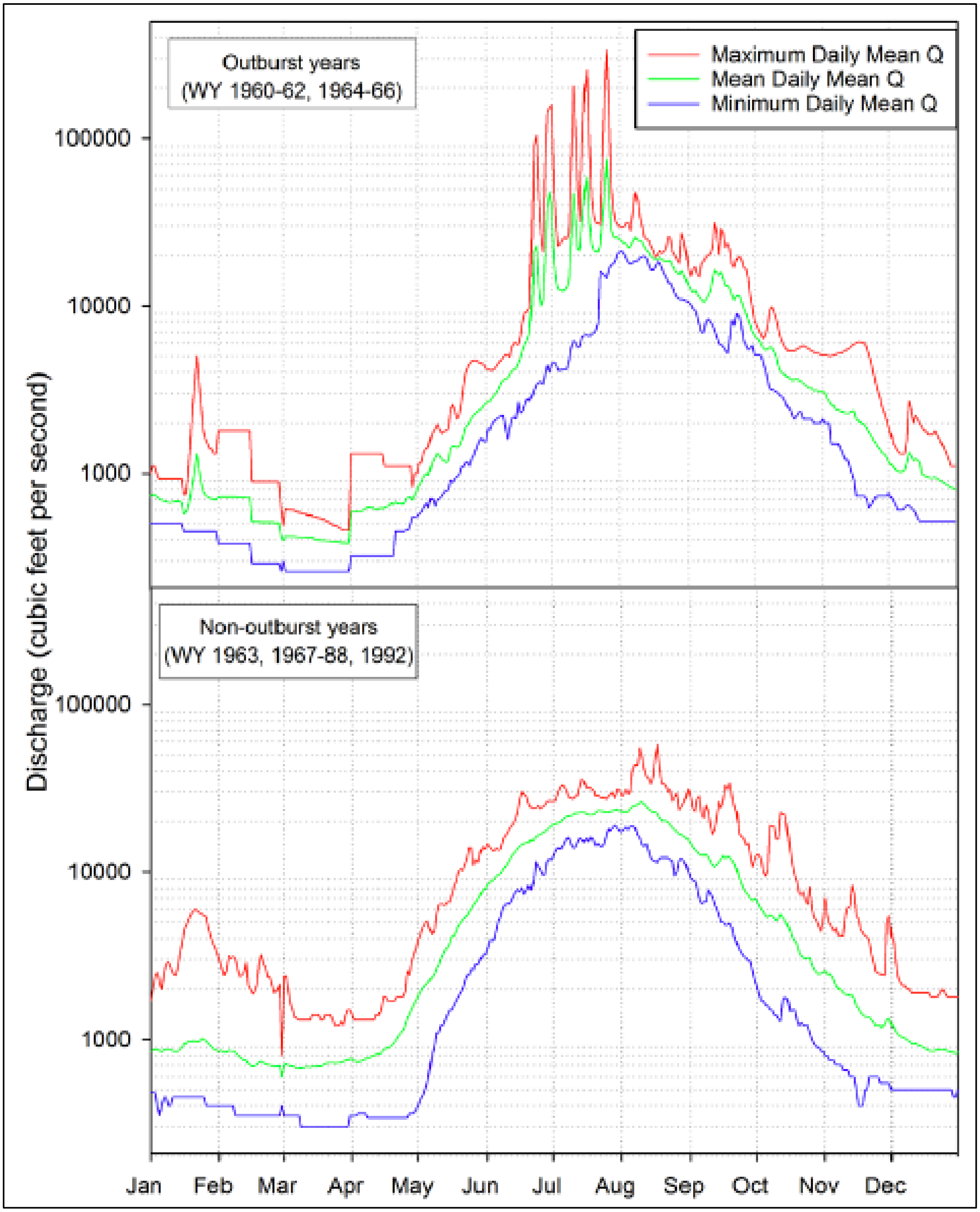


Figure 63. Variation in mean daily discharge on the Knik River for outburst and non-outburst years (Alaska Hydrologic Survey, 2016).

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