Comparing the extent and permanence of headwater streams from two field surveys to values from hydrographic databases and maps

Ken M. Fritz, Elisabeth Hagenbuch, Ellen D'Amico, Molly Reif, Parker. J. Wigington, Jr., Scott G. Leibowitz, Randy L. Comeleo, Joeseph L. Ebersole, and Tracie-Lynn Nadeau[1]

[1]Respectively, Research Ecologist, National Exposure Research Laboratory, US Environmental Protection Agency, Cincinnati, OH; GIS Specialist, Dynamac Corporation, Cincinnati, OH; GIS Specialist, Dynamac Corporation, Cincinnati, OH; GIS Specialist, Dynamac Corporation, Cincinnati, OH at the time this paper was prepared, now Geographer, Joint Airborne Lidar Bathymetry Technical Center of eXpertise, US Army Engineer Research and Development Center, Kiln, MS; Research Hydrologist, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR; Research Ecologist, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR; Ecologist, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR; Research Fisheries Biologist, National Health and Environmental Effects Research Laboratory, US Environmental Protection Agency, Corvallis, OR; Environmental Scientist, Region 10, Oregon Operations Office, US Environmental Protection Agency, Portland OR (26 West Martin Luther King Drive, Cincinnati, OH 45269; E-Mail/Fritz: fritz.ken@epa.gov).

ABSTRACT: Supreme Court cases have questioned if jurisdiction under the Clean Water Act extends to water bodies such as streams without year-round flow. Headwater streams are central to this issue because many periodically dry, and because little is known about their influence on navigable waters. An accurate account of the extent and flow permanence of headwater streams is critical to estimating downstream contributions. We compared the extent and permanence of headwater streams from two field surveys to values from databases and maps. The first used data from 29 headwater streams in nine US forests, whereas the second had data from 178 headwater streams in Oregon. Synthetic networks developed from the nine-forest survey indicated that 33 to 93% of the channel lacked year-round flow. Seven of the nine forests were predicted to have >200% more channel length than portrayed in the high resolution National Hydrography Dataset (NHD). The NHD and topographic map classifications of permanence agreed with ~50% of the field determinations across ~300 headwater sites. Classification agreement with the field determinations generally increased with increasing resolution. However, the flow classification on soil maps only agreed with ~30% of the field determination despite depicting greater channel extent than other maps. Maps that include streams regardless of permanence and size will aid regulatory decisions and are fundamental to improving water quality monitoring and models.

KEY TERMS: headwater streams; flow permanence; hydrography; mapping; ephemeral; intermittent; perennial

INTRODUCTION

Water body mapping provides basic information necessary for the management, protection, and restoration of freshwater resources and the services and benefits (e.g., water quality, flood protection, and wildlife habitat) that they provide to society. Water bodies range greatly in size and their abundances are often inversely related to their sizes (Leopold et al., 1964). Therefore the task of locating and recording the spatial distribution and hydrologic connectivity of smaller water bodies can be more difficult than for their larger counterparts.

Small streams are often called headwater streams because they represent the exterior or most upland links of channel networks. Because of their size, typically shallow channel incision relative to groundwater table elevations, and position in the landscape, many headwater streams are prone to natural drying; however regional and local factors, such as climate, topography, and geology, are important in determining if, when, and where drying will occur (Williams, 2006). The duration, frequency, timing, and predictability of flow or presence of water or saturated conditions (i.e., hydrologic permanence) are used to classify streams (e.g., Hedman and Osterkamp, 1982; Poff and Ward, 1989; Uys and O'Keefe, 1997). Streams that do not experience drying, outside of extreme drought, are called perennial or permanent. In contrast, streams that experience recurrent drying (no water in the stream channel) are called temporary streams. Temporary streams can be broadly divided into either intermittent or ephemeral classes. Intermittent streams have dry and wet (aquatic) phases that are somewhat predictable in time (e.g., seasonal) and have groundwater as a major source (i.e., elevation of the water body's bed is seasonally below the groundwater table). Ephemeral streams flow only in immediate response to hydrologic events such as large rainstorms; they have short, often less predictable aquatic phases and derive water from direct precipitation, surface runoff and/or interflow after precipitation or snowmelt.

A recent US Supreme Court case (*Rapanos v United States* 547 US 715 (2006)), questioned whether the jurisdictional scope of the Clean Water Act (CWA) would extend to headwater streams, particularly those that do not have perennial flow (Nadeau and Rains, 2007; Leibowitz et al., 2008; Caruso, 2011). A database that characterizes the extent and flow permanence of headwater streams would help ease the burden on regulators and the regulated community by reducing the number of disputes and onsite evaluations. Regardless of the details that emerge from future guidance or legislation for jurisdictional determinations, accurate documentation of the geographic extent of headwater streams and their hydrologic permanence is fundamental to CWA jurisdiction, as well as national water quality monitoring and improving water quality models.

Various hydrography resources are used by water resource agencies for decision making. For example, headwater stream designations on 1:24,000-scale topographic maps or Natural Resource Conservation Service (NRCS; formerly Soil Conservation Service) 1:15,840-scale soil maps are used to inform stream classifications in states like Ohio and North Carolina (OHEPA, 2009; NCDWQ, 2010). The National Hydrography Dataset (NHD; http://nhd.usgs.gov/data.html) is the primary digital hydrography resource in the United States and has been used to design a national water quality monitoring program (Paulsen et al., 2008) and to model the transformations and transportation of materials across landscapes (e.g., Alexander et al., 2007).

The NHD is derived from the marriage of two predecessors: US Geological Survey's (USGS) Digitial Line Graphs (DLGs) and US Environmental Protection Agency's (EPA) Reach

File (RF; Dewald and Roth, 1998). The US EPA developed the RF as a spatially referenced database of uniquely identified stream reaches, including aspects such as direction and inter-reach connectivity (Horn and Grayman, 1993). The sources of the geographic base layer of stream lines for the RF versions are the DLGs (Horn and Grayman, 1993). The original geographical positioning of stream DLGs are derived from the digitized stream lines (i.e., “blue lines”) that were delineated on USGS high-resolution (i.e., 1:24,000 scale) and medium-resolution (i.e., 1:100,000 scale) topographic maps for most of the US (e.g., most of Alaska coverage is only available at the 1:250,000 scale). Delineation of streams on USGS 1:24,000-scale (7.5-minute quadrangle) topographic maps was based on interpretations from stereo orthophotographs and verification from field surveys and interviews with local residents, where available (Drummond, 1974; Mark, 1983; Leopold, 1994; K. Roth, USGS, April 8, 2010, personal communication). Because of various updates and corrections to the NHD and the lack of funding to support such updates to topographic mapping, stream depiction on topographic maps do not necessarily correspond with the NHD across the US (K. Roth, USGS, April 8, 2010, personal communication). Perennial and intermittent reaches are differentiated on topographic maps by solid and dashed blue lines, respectively. FCodes are 5-digit identifiers of the feature type and combinations of characteristics and values (USGS 2009). The stream and river reaches are considered as a feature type in the NHD and have different FCodes for perennial (FCode 46006) and intermittent (FCode 46003) reaches.

The standards set out for mapping streams on topographic maps (Chorely and Dale, 1972; Drummond, 1974; Mark, 1983; USGS, 1999; 2009) suggest the following in regards to the topographic maps and NHD coverage of headwater streams: 1) ephemeral channels were meant to be excluded, but could be mistakenly depicted as a result of flow permanence overestimation;

2) individual stream segments recognized as being too short or minor or too close to the watershed boundary were excluded; 3) recognition and delineation of headwater streams may vary because of physiographic properties and seasonality (including the visibility of streams through forest canopies when interpreting from stereo orthophotographs); and 4) fewer headwater streams would be delineated on the 1:100,000-scale maps than on 1:24,000-scale maps. These suggest that the NHD will underestimate the true extent of headwater streams on the landscape, but the documentation of headwater streams will be non-randomly distributed due to the variability of mapping accuracy within the NHD. In fact, previous studies across various geographic areas have consistently found that the extent of headwater streams depicted by the NHD and on topographic maps fall short compared to that determined from field surveys (Morisawa, 1957; Coates, 1958; Hansen, 2001; Heine et al., 2004; Roy et al., 2009; Brooks and Colburn, 2011). Despite these limitations, the NHD is still the most comprehensive digital source currently available for the extent and permanence of headwater streams in the US (Nadeau and Rains, 2007).

Recognizing the limitations of hydrography databases and maps in representing the actual extent and flow permanence of headwaters is important for several reasons. In particular because headwater streams represent a dominant interface between terrestrial and freshwater ecosystems, hydrology is a critical factor influencing pattern and process in river networks, and hydrography is a fundamental tool used in water resource monitoring, modeling, and decision making. The objective of this study was to compare the extent and permanence of headwater streams from field surveys to existing values from national databases and maps. Here we present two case studies comparing the extent and permanence of headwater streams to existing hydrography resources. The first case study used geographical and hydrological data from a study on indicators of hydrologic permanence for forested headwater streams (Fritz et al., 2006; Fritz et al., 2008), hereafter referred to as the Headwater Intermittent Stream Study (HISS). The second case study incorporated data from a study assessing the discriminatory ability of the Streamflow Duration Assessment Method (SDAM), a rapid field-based protocol for classifying the hydrologic permanence of streams in Oregon (Nadeau, 2011).

METHODS

Our approach for evaluating the ability of existing maps to represent headwater stream characteristics consisted of three types of analyses. First, we compared the permanence class (perennial, intermittent, or ephemeral) of headwater reaches as determined by field visits with the permanence class as documented by various map resources. For this analysis, data from the two field studies (HISS and SDAM) were separately compared to data from six different resources (Table S1). Second, network measures of stream order and link magnitude (HISS data only) were compared across mapping resources for each field study. Lastly, we compared channel lengths (total and by flow permanence class) derived from field surveys to those from existing map resources for the catchments containing the nine HISS study forests. The HISS and SDAM analyses are further described below.

HISS study

The HISS sites included 29 headwater streams from nine mesic forests across the contiguous US (Figure 1). All streams drained catchments with >90% forest cover. Seventeen headwater streams from four of the forests (core forests) were monitored for two years (2003 and 2004) and the 12 streams in the remaining five forests (satellite forests) were monitored only one year (2005). Three to four discontinuously spaced stream reaches (30 m long) were positioned longitudinally along each of the headwater streams to establish a range in hydrologic permanence (Fritz et al., 2006). There were a total of 105 stream reaches. The coordinates were recorded for each stream reach using handheld GPS units (WorldNavigator, Teletype Co., Boston, Massachusetts) on personal digital assistants and confirmed with concordance to local topography (Pocket Navigator, Maptech, Inc. Amesbury, Massachusetts). Coordinates were also recorded for channel heads of each stream in the core forests and the Illinois satellite forest. Hydrologic permanence for each of the resulting 105 reaches was determined and recorded as continuous surface flow, interstitial flow (i.e., most of the streambed in shallow habitat units is exposed but flow in these units is visible as trickles or rivulets between stones and/or flow is visible at the tail and head of pools), isolated pools, or dry based on at least two field observations per year. Using spring (April-May) and summer (August-September) field observations of hydrologic status, reaches were classified as having perennial, intermittent, and ephemeral flow regimes. Perennial reaches had either surface flow or interstitial flow during both spring and summer observations. Intermittent reaches had flow during spring but either had isolated pools or were dry in summer. Ephemeral reaches did not have flow during either summer or spring observations. These class assignments based on observations had >80% agreement with the flow classification (following definitions in Hedman and Osterkamp 1982) of reaches using continuous monitoring data (electrical resistance sensors and data loggers) collected at a subset of 69 reaches (Fritz et al., 2006).

We generated synthetic stream networks for each forest using the Arc Hydro Tools extension (http://resources.arcgis.com/content/hydro/surface-water/about) within ArcGIS 10.0 (ESRI, Redlands, California). Ten meter digital elevation models (DEMs; http://seamless.usgs.gov/) were obtained from the National Elevation Dataset (NED) for the encompassing study forest catchments. Our original intent was to delineate study catchments for each forest using the encompassing 12-digit Hydrologic Unit Codes (HUCs; http://nationalmap.gov/viewer.html). However, due to clear discrepancies in the extent of headwater streams depicted among adjacent county-level NRCS soil maps (which were digitized and georeferenced in ArcGIS 10.0) for portions of the study networks within the 12-digit HUCs, we chose not to use entire encompassing 12-digit HUCs. Therefore, we extracted and processed stream networks for portions of the encompassing 12-digit HUCs that had county-level soil maps that comparably depicted the extent of headwater streams. We estimated the extent of ephemeral, intermittent and perennial channels within the study catchments by plotting the coordinates for study reaches and origins and determining the flow accumulation coefficients (FAC) that extended the stream network to within ±10 m of these coordinates. The FAC represents the threshold of the cumulative number of DEM grid cells required to initiate the formation of a stream channel or to reach the origins of perennial or intermittent flow. Where applicable, the origins of the ephemeral, intermittent and perennial flow (sensu Paybins, 2003) were represented as the upstream-most locations having the respective flow permanence field designations. Where we recorded coordinates for multiple channel origins, origins of intermittent flow, and/or origins of perennial flow within a stream network, we determined the range of estimated channel lengths for a given flow class. For each flow class, we determined the best estimate of associated channel length within the networks by identifying the FAC that 1) best described the network structure by incorporating the most field determined tributaries and 2) best estimated the field determined extent of the tributary lengths. To correct for the additional stream length created due to the use of a grid-based stream network, all final generated stream networks were simplified using the “simplify line” tool. A maximum allowable offset value of

10 meters was used in the creation of the simplified stream network to control the streams from being oversimplified.

We compared the total stream lengths from the generated stream networks to those delineated in the high- and medium-resolution NHD flowlines (1:24,000 and 1:100,000 scales, respectively); and to digitized NRCS (1:15,840 scale) stream networks. Field-based determinations of flow permanence class at each reach were compared to flow permanence classes assigned to reaches in the high- and medium-resolution NHD, USGS topographic maps (1:24,000 and 1:100,000 scales), and the digitized NRCS stream networks. Because the NHD, USGS topographic and NRCS soil maps do not delineate streams as being ephemeral, in our comparisons we assumed that stream reaches in our synthetic networks that were not delineated by the NHD or on maps were recognized by those sources as ephemeral stream reaches. In other words, our assessment of permanence classification did not penalize the hydrographic resources for not delineating reaches with ephemeral flow. However, disagreement with our field determinations can result where the hydrography resources depicts ephemeral streams as having intermittent or perennial flow. Lastly for each study reach we compared Strahler stream order and link magnitude determined from the generated stream networks to those determined from the networks delineated in the high- and medium-resolution NHD, USGS topographic and NRCS soil maps. Reaches not depicted in the NHD or on maps were designated as zero-order reaches by the NHD or maps.

SDAM study

The second case study focused on headwater streams in Oregon and will hereafter be referred to as SDAM. For this case study we probabilistically selected study reaches from a population of reaches in Oregon that were stratified to ensure a wide range of flow permanence.

In order to logistically achieve a large sample size, the surveyed population included only headwater reaches that intersected with the census 2000 road network (i.e., primary, secondary, and local, no interstate roads). The population of headwater reaches included three groups. Two of the groups were perennial and intermittent streams delineated on the high-resolution NHD (1:24,000) that intersected with the road network and were near NHD intermittent-perennial transitions and delineated stream ("blue line") origins. The third group was stream-road intersections generated from a synthetic, extended stream network. We generated the extended stream network using the 30-m DEM to extract a statewide raster linear stream network from a gridded flow accumulation dataset and set a 10-ha minimum drainage area threshold. Strahler stream order was assigned to each segment of the synthetic network. We then identified all the additional first-order streams that intersected roads in the extended network. A total of 187 headwater stream reaches were geographically located using GPS between August 2008 and October 2009. Of those, 178 were surveyed during at least one late-summer (i.e., the dry season) period and one early-spring (i.e., the wet season) period to characterize hydrologic permanence. Drainage areas for the sites ranged from 0.01 to 478.5 km^2 We used a combination of dry and wet season assessments of hydrologic condition as described above, electrical resistance sensor data and subsurface (i.e., hyporheic) flow measurements to characterize flow permanence as being ephemeral, intermittent or perennial at the 178 reaches. Hyporheic flow was documented where surface water was observed flowing into alluvium and returning to the surface downstream. Stones on the streambed surface were moved or shallow pits dug in the streambed to confirm the presence of hyporheic flow. Of the 178 reaches, 88 were located east and 90 were located west of the Cascade Range. Generally, areas east of the Cascades are drier than areas to the west due to the rain shadow created by the mountain range. Reach lengths surveyed were either 35 to 40 times the channel width or 30 m, whichever was longer. Reaches were positioned sufficiently upstream of road crossings to reduce the effect road crossings may have had on hydrologic permanence. Field-based determinations of flow permanence were compared to the delineations in the high- and medium-resolution NHD (ArcGIS 9.2 and the ArcHydro tools extension, ESRI, Redlands, California) and on USGS quadrangles (1:24,000, 1:100,000, and 1:250,000 scales; Terrain Navigator, MyTopo, Billings, Montana). Because the NHD and USGS topographic maps do not include most ephemeral streams, in our comparisons we assumed that stream reaches not delineated by NHD or on maps were recognized by those sources as ephemeral stream reaches. Strahler stream order determined from the NHD and topographic maps was also determined for each site and compared between resolutions.

RESULTS

HISS

Total annual and summer precipitation was above normal during the study years except in Washington and Illinois where conditions were dry compared to historic levels (Table 1). Of the 105 headwater stream reaches surveyed, 41% and 71% were not delineated (i.e., no stream lines) as part of the high- and medium-resolution NHD channel networks, respectively (Table 2). As expected, similar percentages of the reaches were not delineated on USGS 1:24,000- (43%) and 1:100,000-scale (72%) topographic maps. Of the 43 reaches not delineated as stream channel by the high-resolution NHD (i.e., those we coded as ephemeral), 14 and 7 were field-determined to have intermittent and perennial flow, respectively. The medium-resolution NHD did not delineate 29 and 24 reaches that were field-determined to have intermittent and perennial flow, respectively. Overall there was approximately 55% and 38% agreement on permanence classification between the field determination and the high- and medium-resolution NHD, respectively (Table 2). The disagreement between NHD and field-based classifications was mainly a result of the NHD tending to underestimate permanence (40% and 58% for high and medium resolutions, respectively) relative to the field determinations (Table 2). While permanence classifications from the soil maps had low agreement (30%) with the field determinations, the extent of the stream networks from the soil maps were more complete than the NHD or topographic maps, delineating approximately 79% of the study reaches as channels in stream networks (Table 2).

Drainage density (i.e., total channel length divided by drainage area) based on best channel length estimates for the synthetic stream networks across the 9 forests (Table 3) ranged from 2.9 to 9.9 km/km^2. Source areas for surveyed channel heads ranged from 0.006 km^2 in Indiana to 0.015 km^2 in southeast Ohio. The percentage of total stream length that had temporary flow regimes (i.e., ephemeral and intermittent) based on best estimates ranged from 33% to 93% (Table 3). Seven of the nine forests were estimated to have substantially greater (201% to 423%) total channel lengths compared to lengths on the high-resolution NHD (Table 4, Figure 2). However, 51 to 71% of the channel length for the synthetic networks was ephemeral and therefore not included in the high-resolution NHD. The differences in combined lengths of intermittent and perennial reaches between synthetic and high-resolution NHD networks varied greatly among forests (Table 4). For instance, the combined lengths of intermittent and perennial channels were comparable between high-resolution NHD and synthetic networks for the forests in Indiana and south central Ohio, but these lengths differed greatly for other locations such as Kentucky and West Virginia.

The distributions of stream order differences for the 105 reaches between the synthetic networks and the NHD and topographic networks were positively skewed (Figure 3). The median difference in stream order was one between the synthetic networks and the NHD and topographic networks across the 105 reaches, but was more positively skewed for the medium resolution than the high resolution. Strahler stream order designation based on the high-resolution NHD network agreed with the synthetic network for ~14% of the study sites. The percent agreement for stream order designation was twice as high between the soil map network and the synthetic network and the median difference was zero. The link magnitudes of the study reaches depicted on soil map networks were also more comparable to the synthetic networks than to those derived from NHD and USGS topographic networks (Figure 4). Only 6 of the 105 study reaches had the same link magnitude derived from the synthetic and high-resolution NHD networks compared to 28 reaches having the same derived from the synthetic and soil map networks.

SDAM

Total annual precipitation for Oregon was below normal (lower tercile of NCDC data) in 2008 and 2009. There were 37 (21%) and 122 (68%) reaches that were not delineated (i.e., no stream line and so classified as ephemeral) on the high- and medium-resolution NHD, respectively (Table 5, Figure 5 shown as zero-order streams). Of the 37 reaches not delineated on the high-resolution NHD, only 7 and 3 were determined to be intermittent and perennial, respectively. However, over half (i.e., 63 of 122) of the stream reaches not delineated on the medium-resolution NHD were either intermittent or perennial (Table 5). Out of the 178 sites, 43%, 66% and 82% were not delineated as streams on USGS 1:24,000-, 1:100,000- and 1:250,000-scale topographic maps, respectively (Table 5, Figure 5 shown as zero-order streams).

The overall percent agreement for permanence classification between the field determinations and the high- and medium-resolution NHD was 42% and 51%, respectively

(Table 5). Across all reaches, the high-resolution NHD generally overestimated flow permanence relative to field determinations, including 43 ephemeral reaches classified as being either intermittent or perennial, whereas the medium-resolution NHD tended to underestimate flow permanence. The overall percent agreement of flow permanence classification between field determinations and the high-resolution NHD across the reaches was 44 and 40% for reaches east and west of the Cascades, respectively. However, the NHD classifications tended to overestimate permanence (i.e., 51% out of a total of 56% disagreement) east of the Cascades, whereas disagreement west of the Cascades was more balanced between overestimation and underestimation of permanence (37% and 23% out of a total of 60% disagreement, respectively).

The overall percent agreement of flow permanence classifications between those on USGS topographic maps and our field determinations ranged from 42 to 50%, and the percentage of permanence underestimation tended to increase with decreasing resolution (Table 5). The overall percent agreement for the 1:24,000-scale topographic maps (50%) was more similar to that of the medium-resolution NHD (51%) than that of the high-resolution NHD (42%). However, percent agreement of flow permanence classifications for only reaches we determined in the field to be intermittent or perennial was comparable for the high-resolution NHD (44%) and the 1:24,000-scale topographic maps (45%). These were higher than those for medium-resolution NHD (30%), 1:100,000-scale maps (20%), and 1:250,000-scale maps (14%).

The median difference of Stahler stream order designations between high- and medium-resolution NHD for the SDAM study reaches was one stream order, but ranged from being identical to being as different as four stream orders (Figure 6A) even when considering only those reaches determined to be perennial (Figure 6B). There was less discrepancy between stream order determined from 1:24,000- and 1:100:000-scale USGS topographic maps where the median difference was zero and ranged from zero to three stream orders for all reaches (Figure 6C) and up to two stream orders for perennial reaches (Figure 6D).

DISCUSSION

Channel extent and flow class are two fundamental pieces of hydrography information that can be used and evaluated from mapping resources. In both case studies described here, a substantial number of headwater streams were not depicted on the NHD and topographic maps. Brooks and Colburn (2011) determined the upstream extent of 83% of surveyed streams in a 385-km^2 watershed in north-central Massachusetts were underestimated based on blue line designations on USGS topographical maps. As expected, the extent of headwater channels depicted by existing mapping resources tended to increase with higher mapping resolution (e.g., 1:24,000 scale > 1:100,000 scale). This is consistent with findings of previous studies in coastal Oregon (Vance-Borland et al., 2009) and in Colorado (Caruso and Haynes, 2011), where 1:100:000-scale maps portrayed only one-third to half the channel length depicted on 1:24,000-scale maps. While the extent of headwater channels depicted on NRCS maps (1:15,840 scale) for the HISS study locations was often much more detailed than those in the NHD and on topographic maps, there were also study locations where the opposite was true (e.g., Washington, New Hampshire). Field surveys in three physiographic provinces in North Carolina determined that NRCS soil maps tended to overestimate the extent of streams, whereas the high-resolution NHD (1:24,000 scale) tended to underestimate them (Colson et al., 2008). Field data from the Chattooga River Basin in Georgia, South Carolina and North Carolina indicated that the 1:100,000- and 1:24,000-scale topographic maps only identified 14% and 21% of the stream network, respectively (Hansen, 2001). These values fall within the ranges for the medium- (7% -

18%) and high-resolution NHD (21 – 33%) we estimated for the seven HISS forests that included ephemeral channel lengths (excludes Washington and New Hampshire).

Flow classification from existing mapping resources only agreed with ~50% of our field determinations across almost 300 headwater reaches. For both case studies, reaches that were determined in the field to be ephemeral were rarely depicted as perennial reaches by mapping resources. Far more common than these were unmapped perennial reaches. The way in which high resolution flow classifications differed from our field determinations generally differed between case studies. Classifications from the NHD and maps tended to underestimate flow permanence relative to HISS field determinations, whereas those for the SDAM reaches tend to overestimate flow permanence. This may be explained in part because the HISS sites were largely in mesic continental regions, whereas the SDAM sites included more coastal and arid regions in Oregon. Previous field surveys across 12 western states also indicated a tendency for the medium-resolution NHD to overestimate hydrologic permanence in arid regions (Stoddard et al., 2005). They found that 30% of the perennial stream lengths depicted on the medium-resolution NHD were determined to be intermittent or ephemeral in the field whereas only 7% of the intermittent stream lengths were found to be perennial (Stoddard et al., 2005). Precipitation at most HISS study locations during field determinations was also above normal, whereas rainfall was below normal across Oregon during the SDAM surveys. Land cover for HISS watersheds was forest, whereas the SDAM catchments drained a broad range of land covers and uses. Headwater streams in forested catchments may have been more difficult for cartographers to discern in orthophotographs than those in non-forested catchments. Inconsistent interpretation among cartographers (Leopold 1994) and varying source material for different parts of the country is another possible explanation for the difference in how the NHD flow classifications disagreed with field determinations between the case studies. The high-resolution NHD for Oregon was based on the best available source dataset, so for some portions of Oregon the NHD delineates more first-order streams than it does for other portions of Oregon and the United States in general (D. Wickwire, Bureau of Land Management, September 5, 2012, personal communication). The NHD is the most comprehensive digital hydrography source for making broad comparisons in the US; however users making regional comparisons might implicitly assume that any error or bias would be systematic across the database. Our findings point out that errors/bias for flow classification of headwater streams is not systematic and argue for careful scrutiny of NHD-based results.

Ephemeral channel represented at least half of the estimated total length in six of the nine HISS synthetic networks and most of that length was not depicted on existing mapping resources. The combined lengths of intermittent and perennial channel depicted in the medium-resolution NHD for each location were also lower than those from our synthetic networks. Unlike channel extent, agreement in terms of flow permanence did not necessarily increase with mapping resolution. For example, there was higher overall agreement between SDAM field determinations and classifications from the medium resolution than from the high-resolution NHD. There was also higher agreement between the HISS field determinations and classification from the 1:24,000-scale topographic maps than from the 1:15,840-scale NRCS maps. In both cases the greater disagreement stemmed from the higher resolution source tending to overestimate flow permanence for headwater reaches. Stream length within a Chattooga basin having temporary flow regimes was estimated to represent 72% of the entire stream network (Hansen, 2001) and was within the range we determined from the HISS case study.

Although there are limitations of using stream order to characterize and compare streams, it is a practical way to stratify stream size (Hughes et al., 2011) and is used as a criterion in jurisdictional determinations (Caruso and Haynes, 2011). The synthetic networks we derived for the HISS locations suggest that most first-order channels are not portrayed in the NHD and on topographic maps, and that many of these are ephemeral. The median stream order difference between field and NHD designations was one stream order for the high- and medium-resolution NHD, but differences could be as high as four stream orders. This is consistent with previous literature dealing with the influence of mapping scale on stream order characterization (Scheidegger, 1966; Hughes and Omernick, 1983). Because we did not survey upstream of the SDAM study reaches, we were unable to determine stream order from the field, however given their small sizes it is likely that most of the channels were first and second order. Based on 1:12,000-scale topographic maps, first- and second-order streams represented about 79% of the total length of coastal and Cascade stream networks in Oregon (Boehne and House, 1983). A field survey of stream channels in the Chattooga River Basin in Georgia, South Carolina and North Carolina determined that 78% of streams were first order and contributed to 59% of the total stream length in the basin (Hansen, 2001). If we assume that all first-order channels are ephemeral, then first-order channels contributed between 49% and 71% of the total length of the HISS networks that had ephemeral channels. However, this range is likely conservative because there were first-order reaches with intermittent and perennial flow and flow class transitions are not limited to confluences where stream order increases.

The discrepancies in channel extent and flow class between NHD resolutions has large implications because the medium-resolution NHD has been used to design national water quality monitoring (Paulsen et al., 2008) and model transport and transformation across landscapes (e.g., Alexander et al., 2007). This excludes a substantial portion of river networks from assessment and potentially underestimates the mediating role of headwater streams as the interface between uplands and downstream waters (Benstead and Leigh 2012). The difference in extent between these NHD resolutions also has large implications on the conservation of aquatic fauna such that critical habitat may be excluded from management plans (e.g., Wigington et al., 2006). Using the medium-resolution NHD, Nadeau and Rains (2007) calculated that 53% (2,900,000 km) of the total stream length in the continental US were headwater (first order) streams and 50% of these were ephemeral and intermittent. Our findings suggest that most streams depicted on the medium-resolution NHD as first-order streams would be determined to be second-order streams in the field and that most first-order channels are not depicted in the medium-resolution NHD. The percentage of reaches that were not depicted in the medium-resolution NHD as channels but were determined to be perennial were 32% (24/75) and 25% (30/122) for HISS and SDAM case studies, respectively. Therefore, the percentage of first-order streams with ephemeral and intermittent flow may be on the order of 68% - 75% based on our findings from these case studies. This is likely a conservative estimate given that we did not have study areas in the more arid regions like the Great Plains and the American Southwest, where higher percentages of first-order streams would be expected to have ephemeral and intermittent flow. Also our estimates of channel length from the HISS case study indicate that the medium-resolution NHD depicts a small percentage (as low as 0 to 15%) of the ephemeral and intermittent channel length in some forested areas.

Existing mapping approaches for channel extent largely depend on identifying the location of channel heads in the landscape. However, in most regions this does not provide the details necessary to characterize flow permanence among headwater reaches of a stream network. The hydrology of most headwater streams is notoriously more variable than larger downstream rivers. For example, surface flow in stream networks draining agricultural catchments in western Oregon expands almost by two orders of magnitude from the dry summers to the wet winters (Wigington et al., 2005). Several field studies have characterized where intermittent flow and perennial flow originate along headwater streams and many of these utilize basin and geomorphic measurements, such as drainage area, drainage density and entrenchment ratio (Paybins, 2003; Rivenbark and Jackson, 2004; Svec et al., 2005; Olson and Brouillette, 2006; Fritz et al., 2008). Although the probability of perennial flow generally increases with increasing drainage area and channel size, thresholds and their probability distributions vary among regions because of differences in climate, topography, soils and geology (Winter, 2007; Jaeger et al., 2007). For example, streams having a 70% probability of being perennial in coastal Oregon had a drainage area of only 0.04 km^2 (Clarke et al., 2008), whereas in Massachusetts, the equivalent probability of being perennial is associated with streams having a drainage area of 1.5 km^2 (Bent and Steeves, 2006). Even within regions there are local factors such as bedrock fractures, headcuts and sediment deposits which govern the distribution of perennial surface flow in headwater streams (Anderson et al., 1997; Steinheimer et al., 1998; Hunter et al., 2005).

Land use and human alteration of headwater channels can also influence the permanence of flows in headwater streams. For example, vegetation changes can alter evapotranspiration losses and therefore surface water yields (Stednick, 1996, Hibbs et al. 2012). Urban development can decrease flow permanence by reducing groundwater recharge, however leaky infrastructure and greater channel incision may sustain surface flows in urban headwater streams. The mean drainage area associated with perennial streams in urban areas of the Cincinnati, Ohio metropolitan area was 0.48 km^2, whereas it was 0.31 km^2 for forested areas (Roy et al., 2009).

Using a field-validated synthetic network, the combination of stream burial and alteration of flow permanence in urban areas lead to an estimated decrease of 93% of ephemeral and 46% of intermittent channels but an increase of 22% of perennial channels compared to forested areas (Roy et al., 2009). It was clear from this study and others that most mapping studies of headwater streams have been done over relatively small areas and where catchments have natural land cover. However, together these studies do illustrate the limitations associated with the existing databases, provide some sense of how the true extent and flow permanence varies across the US and ways in which the national inventory can be improved.

Hydrogeographic databases are important tools for the regulating and regulated community. Regardless whether or not headwater streams are deemed jurisdictional waters, a database that accurately delineates these water bodies would alleviate, or provide an objective means for prioritizing, field visits to confirm existence and associated hydrology. Models, sampling designs or management plans based on limited hydrography will either exclude a significant proportion of the stream network or lump headwater streams with surrounding uplands despite having very different hydrogeomorphic processes and connections (Bishop et al., 2008). Our findings should caution users of hydrographic databases and maps regarding the portrayal of the extent, flow permanence, and topology of headwater stream networks. The cartographic origins of the NHD limit this database from characterizing the extent and permanence of many headwater streams. Depicting the geographic extent and flow permanence are fundamental to understanding the cumulative contributions of headwater streams to navigable water bodies. Compared to perennial and even intermittent counterparts, we know relatively little about the ecology of headwater ephemeral channels which are especially absent from existing hydrographic resources. There have been recent developments in methods to characterize the extent and flow permanence of water resources (e.g., James et al., 2007; Turner and Richter, 2011; Jaeger and Olden, 2012), but there is a need to expand the application of such tools over larger spatial scales in an effort to improve the accuracy of national hydrographic resources.

Supporting Information

Additional supporting information may be found in the online version of this article: Table S1 Hydrogeographic resources used for comparisons.

ACKNOWLEDGEMENTS

We thank US EPA Regions 1, 3, 4, 5, 9, and 10, Vermont Department of Environmental Conservation, and West Virginia Department of Environmental protection for logistical and field support for HISS. Amy Prues, Brad Autrey, Karen Blocksom, Joe Flotemersch, Brent Johnson, Chuck Lane, Michael Moeykens, Eric O'Neal, Allison Roy, Jason Taylor, David Walters, and Lori Winters provided field or technical support for HISS. We also thank Chris Barton and Will Marshall (Robinson Forest), Rebecca Ewing (Wayne National Forest), Anne Timm (Hoosier National Forest), Mike Welker (Shawnee National Forest), and Peter Whan (Edge of Appalachia Preserve) for facilitating the research at various HISS locations. We are grateful to Brian Topping, Rob Coulombe, Blake Hatteberg, Lindsey Webb, Jess Jordan, Shawn Majors, Mike Turaski, and Rachel Lovellford for providing logistical and field support for the SDAM study. Special thanks to Heather Sanders, Jay Christensen, Brian Caruso, and three anonymous reviewers for comments on earlier versions of the paper. The US EPA through its Office of Research and Development partially funded and collaborated in the research described here under contracts EP-D-06-096 and EP-D-11-073 to Dynamac Corporation. Although this work was reviewed by EPA and approved for publication, it might not necessarily reflect official

Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Literature cited

Alexander, R. B., E. W. Boyer, R. A. Smith, G. E. Schwarz, and R. B. Moore, 2007. The Role of Headwater Streams in Downstream Water Quality. Journal of the American Water Resources Association 43:41-59.

Anderson, S. P., W. E. Dietrich, D. R. Montgomery, R. Torres, M. E. Conrad, and K. Loague, 1997. Subsurface Flow Paths in a Steep, Unchanneled Catchment. Water Resources Research 33:3637-2653.

Benstead, J. P. and D. S. Leigh, 2012. An Expanded Role for River Networks. Nature Geoscience 5:678-679.

Bent, G. C. and P. A. Steeves. 2006. A Revised Logistic Regression Equation and An Automated Procedure for Mapping the Probability of a Stream Flowing Perennially in Massachusetts. US Geological Survey Scientific Investigations Report 2006–5051, 107p. http://pubs.usgs.gov/sir/2006/5031/, *accessed* February 19, 2013

Bishop, K., I. Buffam, M. Erlandsson, J. Fölster, H. Laudon, J. Seibert, and J. Temnerud, 2008. Aqua Incognita: The Unknown Headwaters. Hydrological Processes 22:1239-1242.

Boehne, P. L. and R. A. House, 1983. Stream Ordering: A Tool for Land Managers to Classify Western Oregon Streams. US Bureau of Land Management, Technical Note OR-3. Portland, Oregon.

Brooks, R. T. and E. A. Colburn, 2011. Extent and Channel Morphology of Unmapped Headwater Stream Segments of the Quabbin Watershed, Massachusetts. Journal of the American Water Resources Association 47:158-168.

Caruso, B. S., 2011. Science and Policy Integration Issues for Stream and Wetland Jurisdictional Determinations in a Semi-arid Region of Western U.S. Wetlands Ecology and Management 19:351-371.

Caruso, B. S. and J. Haynes, 2011. Biophysical-Regulatory Classification and Profiling of Streams Across Management Units and Ecoregions. Journal of the American Water Resources Association 47:389-407.

Chorley, R. J. and P. F. Dale, 1972. Cartographic Problems in Stream Channel Delineation. Cartography 7:150-162.

Clarke, S. E., K. M. Burnett, and D. J. Miller, 2008. Modeling Streams and Hydrogeomorphic Attributes in Oregon from Digital and Field Data. Journal of the American Water Resources Association 44:459-477.

Coates, D. R., 1958. Quantitative Geomorphology of Small Drainage Basins of Southern Indiana. Office of Naval Research Project NR 389-042, Technical Report 10, Department of Geography, Columbia University, New York.

Colson, T., J. Gregory, J. Dorney, and P. Russell, 2008. Topographic and Soil Maps Do Not Accurately Depict Headwater Stream Networks. National Wetland Newsletter 30:25-28.

Dewald, T. G. and K. S. Roth, 1998. The National Hydrography Dataset – Integrating the USEPA Reach File and USGS DLG. *In*: Proceedings of the 1998 ESRI User Conference, July 27-31, 1998. Environmental Systems Research Institute, Redlands, California.

Drummond, R. R., 1974. When Is a Stream a Stream? The Professional Geographer 26:34-37.

Fritz, K. M., B. R. Johnson, and D. M. Walters, 2006. Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams. EPA 600/R-06/126. USEPA Office of Research and Development, National Exposure Research Laboratory, Cincinnati, Ohio.

Fritz, K. M., B. R. Johnson, and D. M. Walters, 2008. Physical Indicators of Hydrologic Permanence in Forested Headwater Streams. Journal of the North American Benthological Society 27:690-704.

Hansen, W. F., 2001. Identifying Stream Types and Management Implications. Forest Ecology and Management 143:39-46.

Hedman, E. R. and W. R. Osterkamp, 1982. Streamflow Characteristics Related to Channel Geometry of Streams in Western United States. US Geological Survey Water-Supply Paper 2193, 17p. http://pubs.usgs.gov/wsp/2193/report.pdf, *accessed* February 19, 2013.

Heine, R. A., C.L. Lant, and R. R. Sengupta, 2004. Development and Comparison of Approaches for Automated Mapping of Stream Channel Networks. Annals of the Association of American Geographers 94:477-490.

Hibbs, B.J., W. Hu, and R. Ridgway, 2012. Origin of Stream Flows at the Wildlands-Urban Interface, Santa Monica Mountains, California, U.S.A. Environmental & Engineering Geoscience 18:51-64.

Horn, C. R. and W. M. Grayman, 1993. Water-quality Modeling with EPA Reach File System. Journal of Water Resources Planning and Management 119:262-274.

Hughes, R. M., P. R. Kaufmann, and M. H. Weber, 2011. National and regional comparisons between Strahler order and stream size. Journal of the North American Benthological Society 30:103-121.

Hughes, R. M. and J. M. Omernick, 1983. An Alternative for Characterizing Stream Size. *In*: Dynamics of Lotic Ecosystems, T. D. Fontaine and S. M. Bartell (Editors). Ann Arbor Science, Ann Arbor Michigan, pp. 87-101.

Hunter, M. A., T. Quinn, and M. P. Hayes, 2005. Low Flow Spatial Characteristics in Forested Headwater Channels of Southwest Washington. Journal of the American Water Resources Association 41:503-516.

Jaeger, K. L., D. R. Montgomery, and S. M. Bolton, 2007. Channel and Perennial Flow Initiation in Headwater Streams: Management Implications of Variability in Source-area Size. Environmental Management 40:775-786.

Jaeger, K. L. and J.D. Olden, 2012. Electrical resistance sensor arrays as a means to quantify longitudinal connectivity of rivers. River Research and Applications 28:1843-1852.

James, L. A., D. G. Watson, and W. F. Hanson, 2007. Using LiDAR Data to Map Gullies and Headwater Streams Under Forest Canopy: South Carolina, USA. Catena 71:132-144.

Leibowitz, S. G., P. J. Wigington Jr., M. C. Rains, and D. M. Downing, 2008. Non-navigable Streams and Adjacent Wetlands: Addressing Science Needs Following the Supreme Court’s Rapanos Decision. Frontiers in Ecology and the Environment 6:364-371.

Leopold, L. B., 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts.

Leopold, L. B., M. G. Wolman, and J. P. Miller, 1964. Fluvial Processes in Geomorphology. W. H. Freeman and Company, San Francisco, California.

Mark, D. M., 1983. Relations Between Field-surveyed Channel Networks and Map-based Geomorphometric Measures, Inez, Kentucky. Annals of the Association of American Geographers 73:358-372.

Morisawa, M., 1957. Accuracy of Determination of Stream Lengths from Topographic Maps. Transactions of the American Geophysical Union 38:86-88.

Nadeau, T.-L., 2011. Streamflow Duration Assessment Method for Oregon, U.S. Environmental Protection Agency, Region 10, Document No. EPA910-R-11-002. http://www.epa.gov/region10/pdf/water/sdam/final_sdam_oregon_nov2011.pdf, *accessed* February 19, 2013.

Nadeau, T.-L. and M. C. Rains, 2007. Hydrological Connectivity Between Headwater Streams and Downstream Waters: How Science Can Inform Policy. Journal of the American Water Resources Association 43:118-133.

NCDWQ (North Carolina Division of Water Quality), 2010. Methodology for Identification of Intermittent and Perennial Streams and Their Origins (Version 4.11). North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, North Carolina. http://portal.ncdenr.org/c/document_library/get_file?uuid=0ddc6ea1-d736-4b55-8e50-169a4476de96&groupId=38364, *accessed* February 19, 2013.

OHEPA (Ohio Environmental Protection Agency), 2009. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams. Review Version 2.3. Division of Surface Water, Ohio Environmental Protection Agency, Columbus, Ohio. http://www.epa.state.oh.us/portals/35/wqs/headwaters/PHWHManual_2009.pdf, *accessed* February 19, 2013.

Olson, S. A. and M. C. Brouillette, 2006. A Logistic Regression Equation for Estimating the Probability of a Stream in Vermont Having Intermittent Flow. US Geological Survey Scientific Investigations Report 2006–5217, 15p. US Geological Survey, Reston, Virginia.

Paulsen, S. G., A. Mayio, D. V. Peck, J. L. Stoddard, E. Tarquinio, S. M. Holdsworth, J. Van Sickle, L. L. Yuan, C. P. Hawkins, A. T. Herlihy, P. R. Kaufmann, M. T. Barbour, D. P. Larsen, and A. R. Olsen, 2008. Condition of Stream Ecosystems in the US: An Overview of the First National Assessment. Journal of the North American Benthological Society 27:812-821.

Paybins, K. S., 2003. Flow Origin, Drainage Area, and Hydrologic Characteristics for Headwater Streams in the Mountaintop Coal-mining Region of Southern West Virginia, 2000–01. US Geological Survey Water-Resources Investigations Report 02–4300, 20p. http://pubs.usgs.gov/wri/wri02-4300/, *accessed* February 19, 2013.

Poff, N. L. and J. V. Ward, 1989. Implications of Streamflow Variability for Lotic Community Structure: A Regional Analysis of Streamflow Patterns. Canadian Journal of Fisheries and Aquatic Sciences 46:1805-1817.

Rivenbark, B. L. and C. R. Jackson, 2004. Average Discharge, Perennial Flow Initiation, and Channel Initiation – Small Southern Appalachian Basins. Journal of the American Water Resources Association 40:639-646.

Roy, A. H., A. L. Dybas, K. M. Fritz, and H. R. Lubbers, 2009. Urbanization Affects the Extent and Hydrologic Permanence of Headwater Streams in a Midwestern US Metropolitan Area. Journal of the North American Benthological Society 28: 911-928.

Scheidegger, A. E., 1966. Effect of Map Scale on Stream Orders. Hydrological Sciences Journal 11:56-61.

Stednick, J. D., 1996. Monitoring the Effects of Timber Harvest on Annual Water Yield. Journal of Hydrology 176:79-95.

Steinheimer, T. R., K. D. Scoggin, and L. A. Kramer, 1998. Agricultural Chemical Movement Through a Field-Size Watershed in Iowa: Surface Hydrology and Nitrate Losses in Discharge. Environmental Science & Technology 32:1048-1052.

Stoddard, J. L., D. V. Peck, A. R. Olsen, D. P. Larsen, J. Van Sickle, C. P. Hawkins, R. M. Hughes, T. R. Whittier, G. Lomnicky, A. T. Herlihy, P. R. Kaufmann, S. A. Peterson, P. L. Ringold, S. G. Paulsen, and R. Blair, 2005. Environmental Monitoring and Assessment Program (EMAP) Western Streams and Rivers Statistical Summary. EPA 620/R-05/006. Office of Research and Development, US Environmental Protection Agency, Washington, DC. http://www.epa.gov/ wed/pages/publications/authored/EPA620R-05006EMAPWStatisticalSummaryForDistribution.pdf, *accessed* February 19, 2013.

Svec, J. R., R. K. Kolka, and J. W. Stringer, 2005. Defining Perennial, Intermittent, and Ephemeral Channels in Eastern Kentucky: Application to Forestry Best Management Practices. Forest Ecology and Management 214:170–182.

Turner, D.S. and H.E. Richter. 2011. Wet/Dry Mapping: Using Citizen Scientists to Monitor the Extent of Perennial Surface Flow in Dryland Regions. Environmental Management 47:497-505.

USGS (US Geological Survey), 1999. Map Accuracy Standards. USGS Fact Sheet 171-99. http://pubs.usgs.gov/fs/1999/0171/, *accessed* February 19, 2013.

USGS (US Geological Survey), 2009. National Hydrography Dataset Features Catalog – Based on 1:24,000-scale USGS Topographic Map Content. http://nhd.usgs.gov/NHDFeatureCatalog.pdf, *accessed* February 19, 2013

Uys, M. C. and J. H. O'Keefe, 1997. Simple Words and Fuzzy Zones: Early Directions for Temporary River Research in South Africa. Environmental Management 21:517-531.

Vance-Borland, K., K. Burnett, and S. Clarke. 2009. Influence of Mapping Resolution on Assessments of Stream and Streamside Conditions: Lessons from Coastal Oregon, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 19:252-263.

Wigington, P. J., Jr., J. L. Ebersole, M. E. Colvin, S. G. Leibowitz, B. Miller, B. Hansen, H. R. Lavigne, D. White, J. P. Baker, M. R. Church, J. R. Brooks, M. A. Cairns, and J. E. Compton, 2006. Coho Salmon Dependence on Intermittent Streams. Frontiers in Ecology and the Environment 4:513-518.

Wigington, P. J., Jr., T. J. Moser, and D. R. Lindeman, 2005. Stream Network Expansion: A Riparian Water Quality Factor. Hydrological Processes 19:1715-1721.

Williams, D. D., 2006. The Biology of Temporary Waters. Oxford University Press, Oxford, United Kingdom.

Winter, T. C., 2007. The Role of Ground Water in Generating Streamflow in Headwater Areas and in Maintaining Base Flow. Journal of the American Water Resources Association 43:15–25.

Table 1. Precipitation ranks (1 = wettest year or summer on record) derived from nearby National Weather Service stations with daily records >50 y. na = not available (National Weather Service data incomplete), - = not applicable to study periods because survey data were collected before that period.

		Precipitation ranks (rank / y on record)	
Study location	Year	Annual	June - September
IN	2003	20/101	15/108
	2004	35/101	55/108
KY	2003	18/71	14/78
	2004	2/71	8/78
SC OH	2003	na	10/95
	2004	19/84	40/95
SE OH	2003	1/75	3/80
	2004	2/75	5/80
IL	2004	50/60	64/67
	2005	44/60	-
NH	2005	1/66	7/69
VT	2005	18/103	31/104
WA	2004	48/58	9/62
	2005	49/58	-
WV	2004	5/79	13/80
	2005	17/79	-

Table 2. Confusion matrices for 105 HISS headwater reaches comparing field determined hydrologic permanence and information from the National Hydrographic Dataset (NHD; 1:24,000 scale [high resolution] and 1:100, 000 scale [medium resolution]) from topographic maps (1:24,000 and 1:100,000 scales), and from digitized National Resources Conservation Service (NRCS) soil maps (1:15,840 scale). Notes: E = ephemeral (no Fcode in NHD or no line on maps), I = intermittent (Fcode = 46003 or line dashed on maps), and P = perennial (Fcode = 46006 or line solid on maps). Bold values are the number of reaches with agreement between field determination and NHD or map hydrologic permanence classes. Errors of omission describe the instances where the mapping resource omitted reaches of a flow class that were classified in the field whereas errors of commission describe the instances where the mapping resource falsely identifies the flow class of reaches documented in the field. Overestimate describes the percentage of sites where the predicted class from the database or maps had higher permanence than that determined in the field (sum of sites to the right of the diagonal divided by the matrix total (105)). Underestimate describes the percentage of sites where the predicted class from the database or maps had lower permanence than that determined in the field (sum of sites to the left of the diagonal divided by the matrix total (105)).

Field determination	NHD high			
	E	I	P	Errors of omission
E	**22**	0	0	0/22 = 0.0%
I	14	**20**	5	19/39 = 48.7%
P	7	21	**16**	28/44 = 63.6%
Errors of commission	21/43 = 48.8%	21/41 = 51.2%	5/21 = 31.2%	Overall disagreement: 44.8% overestimate: 4.8% underestimate: 40.0%

Field determination	NHD medium			
	E	I	P	Errors of omission
E	**22**	0	0	0/22 = 0.0%
I	29	**6**	4	33/39 = 15.4%
P	24	8	**12**	32/44 = 72.7%
Errors of commission	53/75 = 70.7%	8/14 = 57.1%	4/16 = 25.0%	Overall disagreement: 61.9% overestimate: 3.8% underestimate: 58.1%

Field determination	1:24K TOPO			
	E	I	P	Errors of omission
E	**22**	0	0	0/22 = 0.0%
I	16	**16**	7	23/39 = 59.0%
P	7	11	**26**	18/44 = 40.9%
Errors of commission	23/45 = 51.1%	11/27 = 40.7%	7/33 = 21.2%	Overall disagreement: 39.0% overestimate: 6.7% underestimate: 32.4%

Field determination	1:100K TOPO			
	E	I	P	Errors of omission
E	**21**	0	1	1/22 = 4.5%
I	31	**4**	4	35/39 = 89.7%
P	24	6	**14**	30/44 = 68.2%
Errors of commission	55/76 = 72.4%	6/10 = 60.0%	5/19 = 26.3%	Overall disagreement: 62.8% overestimate: 4.8% underestimate: 58.1%

Field determination	NRCS			
	E	I	P	Errors of omission
E	**7**	14	1	15/22 = 68.2%
I	10	**22**	7	17/39 = 43.6%
P	5	36	**3**	41/44 = 93.2%
Errors of commission	15/22 = 68.2%	50/72 = 69.4%	8/11 = 72.7%	Overall disagreement: 69.5% overestimate: 20.9% underestimate: 48.6%

Table 3. Best estimate of generated channel lengths (ranges) for the nine HISS networks. Notes: Best estimated lengths were generated from the flow accumulation coefficients that best captured the field survey of origins, see text for more details. Ranges are shown for networks where multiple origins of a flow type were surveyed. E = ephemeral; I = intermittent; and P = perennial.

Study location	Area (km^2)	Best estimated length (range; km)			
		E	I	P	Total
IN[1]	100.6	361.2 (361.2 – 618.8)	156.1 (111.8 – 193.3)	38.4	555.7 (511.4 – 850.6)
KY[1]	30.8	112.2 (86.3 - 141.2)	53.6 (52.6 – 70.2)	31.5 (25.1 – 47.8)	197.3 (164.0 – 259.1)
SC OH[1]	30.1	111.8 (94.6 – 214.1)	0.0	46.5 (45.0 – 51.7)	158.3 (139.6 – 265.8)
SE OH[1]	45.5	269.0 (242.1 – 310.9)	141.7 (76.1 – 193.9)	38.6 (26.5 – 46.6)	449.4 (344.7 – 551.4)
IL[1]	95.5	246.0 (154.4 – 532.8)	212.4 (205.0 – 266.9)	44.7	503.1 (404.1 – 844.3)
NH	36.7	-	43.8	33.0	76.8
VT	41.2	113.6	72.2	25.5	211.3
WA	46.9	-	45.0	91.2 (43.6 – 91.2)	136.2 (88.6 – 136.2)
WV	80.5	183.0 (121.7 – 313.1)	0.0	177.7 (121.7 – 283.0)	360.7 (243.4 – 596.1)

[1] Total lengths based on distances downstream from the surveyed channel head origins, remaining forests based on downstream distances from the upstream-most reaches surveyed.

Table 4. Percent differences between best estimated lengths from generated (Table 3) and mapped stream lengths for total channel length and intermittent and perennial channel length (I+P) from areas draining the nine HISS locations. Notes: Mapped stream lengths derived from the medium- (1:100,000 scale) and high-(1:24,000 scale) resolution National Hydrography Dataset (NHD) and from digitized National Resources Conservation Service (NRCS) soil maps (1:15,840 scale).

Study location	NHD medium % difference		NHD high % difference		NRCS % difference	
	Total	I+P	Total	I+P	Total	I+P
IN	1331.0	401.0	210.4	8.7	-6.6	-67.3
KY	542.2	176.9	373.4	104.2	126.8	-2.2
SC OH	496.5	75.2	267.2	7.8	14.2	-66.5
SE OH	974.0	331.1	423.7	110.2	147.0	-0.8
IL	455.7	183.9	201.9	54.2	15.8	-40.8
NH	-	12.8	-	-11.1	-	50.6
VT	1291.8	543.5	223.1	49.4	275.4	73.6
WA	-	219.1	-	-35.4	-	381.4
WV	459.8	175.8	306.6	100.3	87.8	-7.5

Table 5. Confusion matrices for 178 headwater streams in Oregon comparing field determined hydrologic permanence and information from the high-(1:24,000 scale) and medium-resolution (1:100,000 scale) National Hydrographic Dataset and from topographic maps (1:24,000, 1:100,000, and 1:250,000 scales). Notes: E = ephemeral (no Fcode in NHD or no line on topographic maps), I = intermittent (Fcode = 46003 or line dashed on topographic maps), and P = perennial (Fcode = 46006 or line solid on topographic maps). Bold values are the number of streams with agreement between field determination and NHD or topographic hydrologic permanence classes. Errors of omission describe the instances where the mapping resource omitted reaches of a flow class that were classified in the field whereas errors of commission describe the instances where the mapping resource falsely identifies the flow class of reaches documented in the field. Overestimate describes the percentage of sites where the predicted class from the database or maps had higher permanence than that determined in the field (sum of sites to the right of the diagonal divided by the matrix total (178)). Underestimate describes the percentage of sites where the predicted class from the database or maps had lower permanence than that determined in the field (sum of sites to the left of the diagonal divided by the matrix total (178)).

Field determination	NHD high			
	E	I	P	Errors of omission
E	**27**	33	10	43/70 = 61.4%
I	7	**21**	35	42/63 = 66.7%
P	3	15	**27**	18/45 = 40.0%
Errors of commission	10/37 = 27.0%	48/69 = 69.6%	45/72 = 62.5%	Overall disagreement: 57.9% overestimate: 43.8% underestimate: 14%

Field determination	NHD medium			
	E	I	P	Errors of omission
E	**59**	10	1	11/70 = 15.7%
I	33	**22**	8	41/63 = 65.1%
P	30	5	**10**	35/45 = 77.8%
Errors of commission	63/122 = 51.6%	15/37 = 40.5%	9/19 = 47.4%	Overall disagreement: 48.9% overestimate: 10.7% underestimate: 38.2%

Field determination	1:24K TOPO			
	E	I	P	Errors of omission
E	**40**	21	9	30/70 = 42.8%
I	16	**25**	22	38/63 = 60.3%
P	20	1	**24**	21/45 = 46.7%
Errors of commission	36/76 = 47.4%	22/47 = 46.8%	31/55 = 56.4%	Overall disagreement: 50.0% overestimate: 29.2% underestimate: 20.8%

Field determination	1:100K TOPO			
	E	I	P	Errors of omission
E	**53**	0	17	17/70 = 24.3%
I	35	**8**	20	55/63 = 87.3%
P	30	1	**14**	31/45 = 68.9%
Errors of commission	65/118 = 55.1%	1/9 = 11.1%	37/51 = 72.5%	Overall disagreement: 57.9% overestimate: 20.8% underestimate: 37.1%

Field determination	1:250K TOPO			
	E	I	P	Errors of omission
E	**62**	5	3	8/70 = 11.4%
I	50	**8**	5	55/63 = 87.3%
P	35	3	**7**	38/45 = 84.4%
Errors of commission	85/147 = 57.8%	8/16 = 50.0%	8/15 = 53.3%	Overall disagreement: 56.7% overestimate: 7.3% underestimate: 49.4%

Figure headings

Figure 1. Study forest locations for the Headwater Intermittent Streams Study (HISS).

Figure 2. Stream networks for a representative portion of the Kentucky study catchment comparing the synthetic stream network generated from field surveys of channel and flow origins (A), the digitized National Resources Conservation Service (NRCS) soil map (B; 1:15,840 scale), the high-resolution National Hydrogeography Dataset (NHD) flowlines (C; 1:24,000 scale), and the medium-resolution NHD flowlines (D; 1:100,000 scale).

Figure 3. Distribution of Strahler stream order differences for the 105 HISS reaches based on the synthetic stream network generated from field surveys and stream networks from the high-resolution (1:24,000 scale) National Hydrogeography Dataset (NHD; A), medium-resolution (1:100,000 scale) NHD (B), USGS 1:24,000-scale topographic maps (C), USGS 1:100,000-scale topographic maps (D), and digitized NRCS 1:15,840-scale soil maps (E).

Figure 4. Biplots of the link magnitude of the 105 HISS study reaches for the generated synthetic stream networks compared to the high-resolution (1:24,000 scale) National Hydrogeography Dataset (NHD; A), medium-resolution (1:100,000 scale) NHD (B), USGS 1:24,000-scale topographic maps (C), USGS 1:100,000-scale topographic maps (D), and digitized National Resources Conservation Service (NRCS) soil map (1:15,840 scale, E). The dashed lines represent 1:1.

Figure 5. Percent distribution of all Oregon study reaches (n = 187) across Strahler stream order based on the high- (1:24,000 scale) and medium-resolution (1:100,000 scale) National Hydrographic Dataset (NHD) and USGS topographic maps (1:24,000, 1:100,000, and 1:250,000 scales). Reaches shown as zero-order streams were not delineated as streams by NHD (no Fcode) or on topographic maps (no blue line).

Figure 6. Distribution of Strahler stream order differences of the Oregon study reaches based on stream networks from the high-resolution (1:24,000 scale) National Hydrogeography Dataset (NHD) and medium-resolution (1:100,000 scale) NHD for all reaches (n = 187; A) and for only perennial reaches (n = 50; B); from USGS 1:24,000- and 1:100,000-scale topographic maps for all reaches (C) and for only perennial reaches (D).

Figure 1

Figure 2

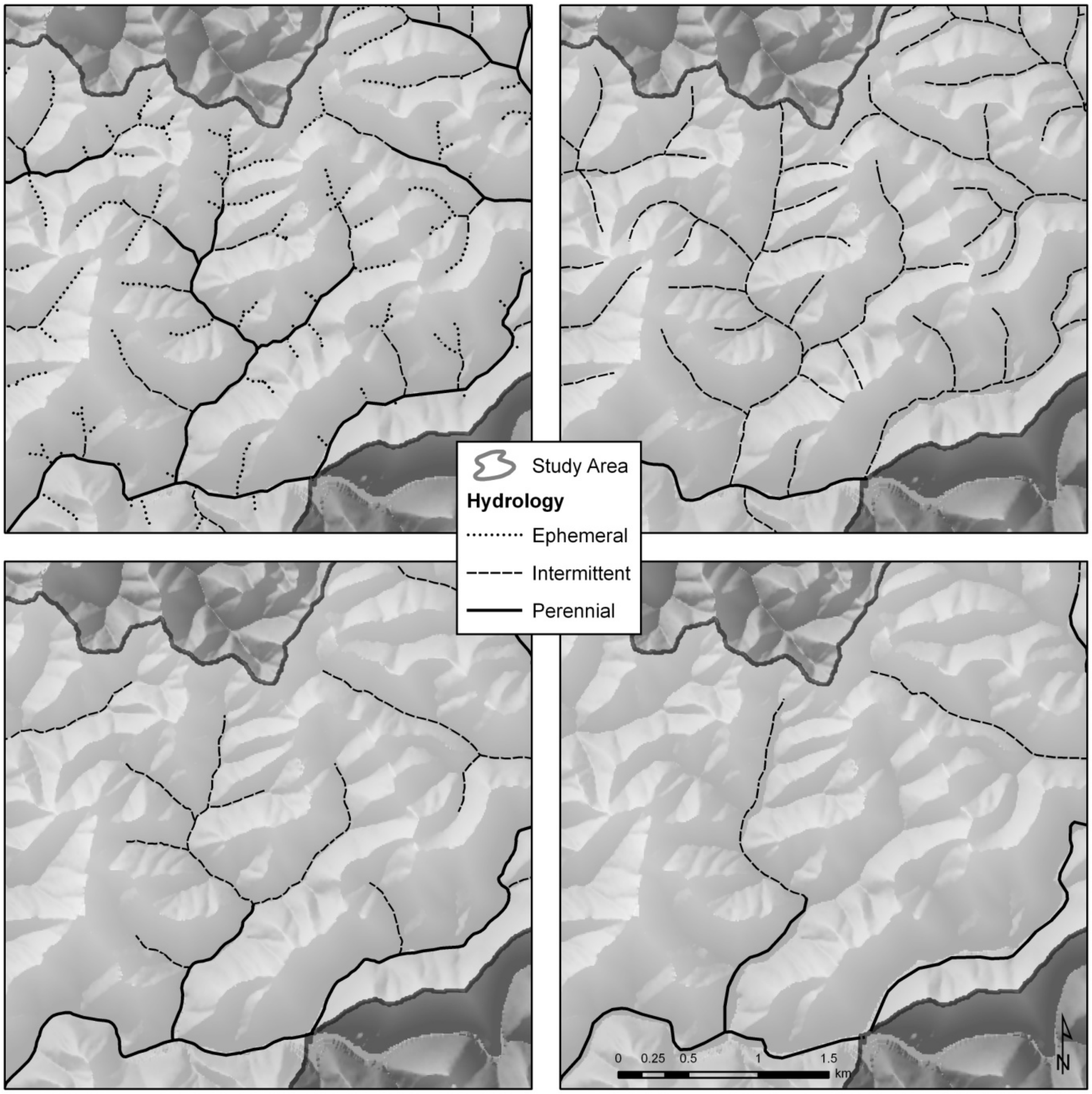
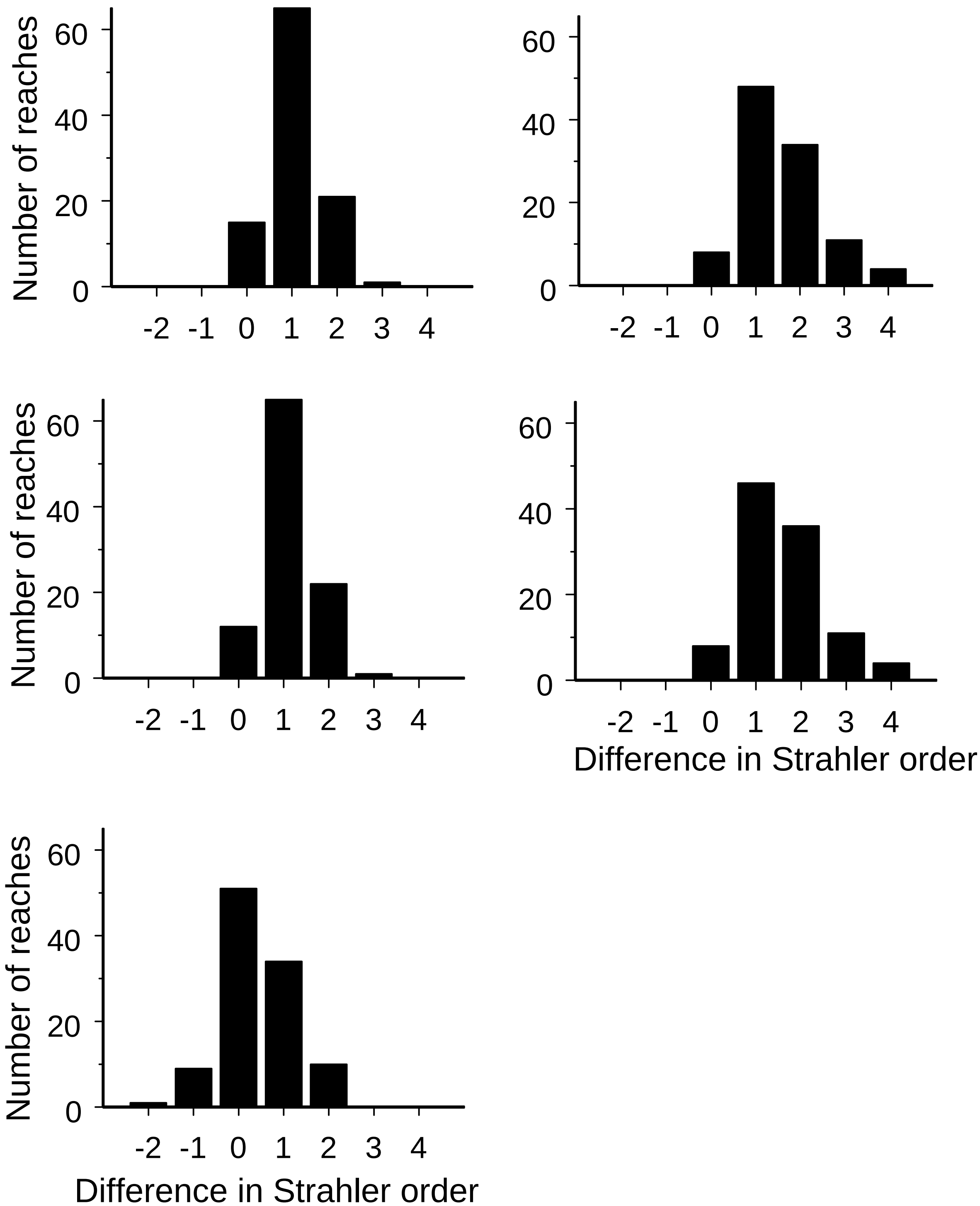
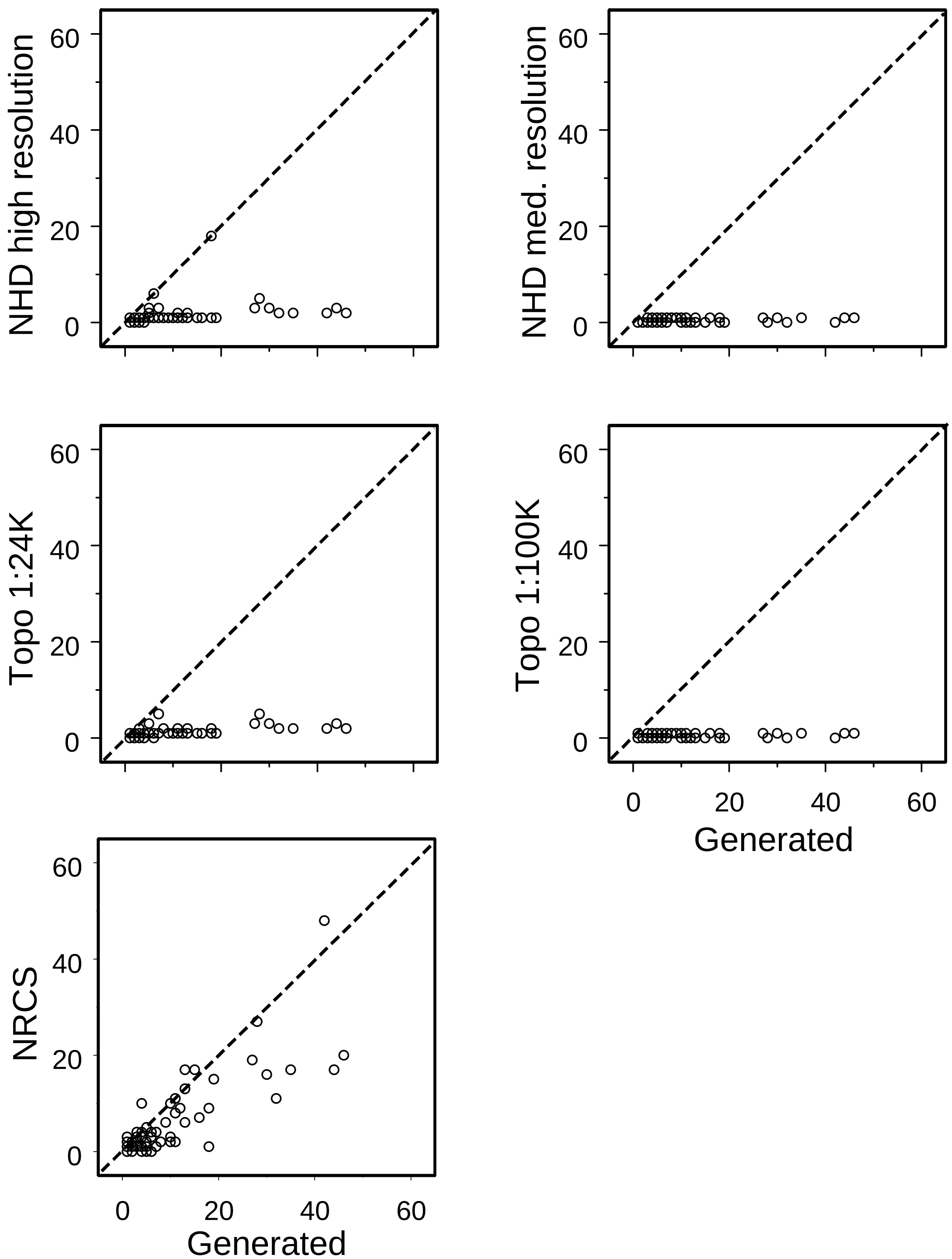

Study Area
Hydrology
Ephemeral
Intermittent
Perennial
0 0.25 0.5 1 1.5
km
N

Figure 3



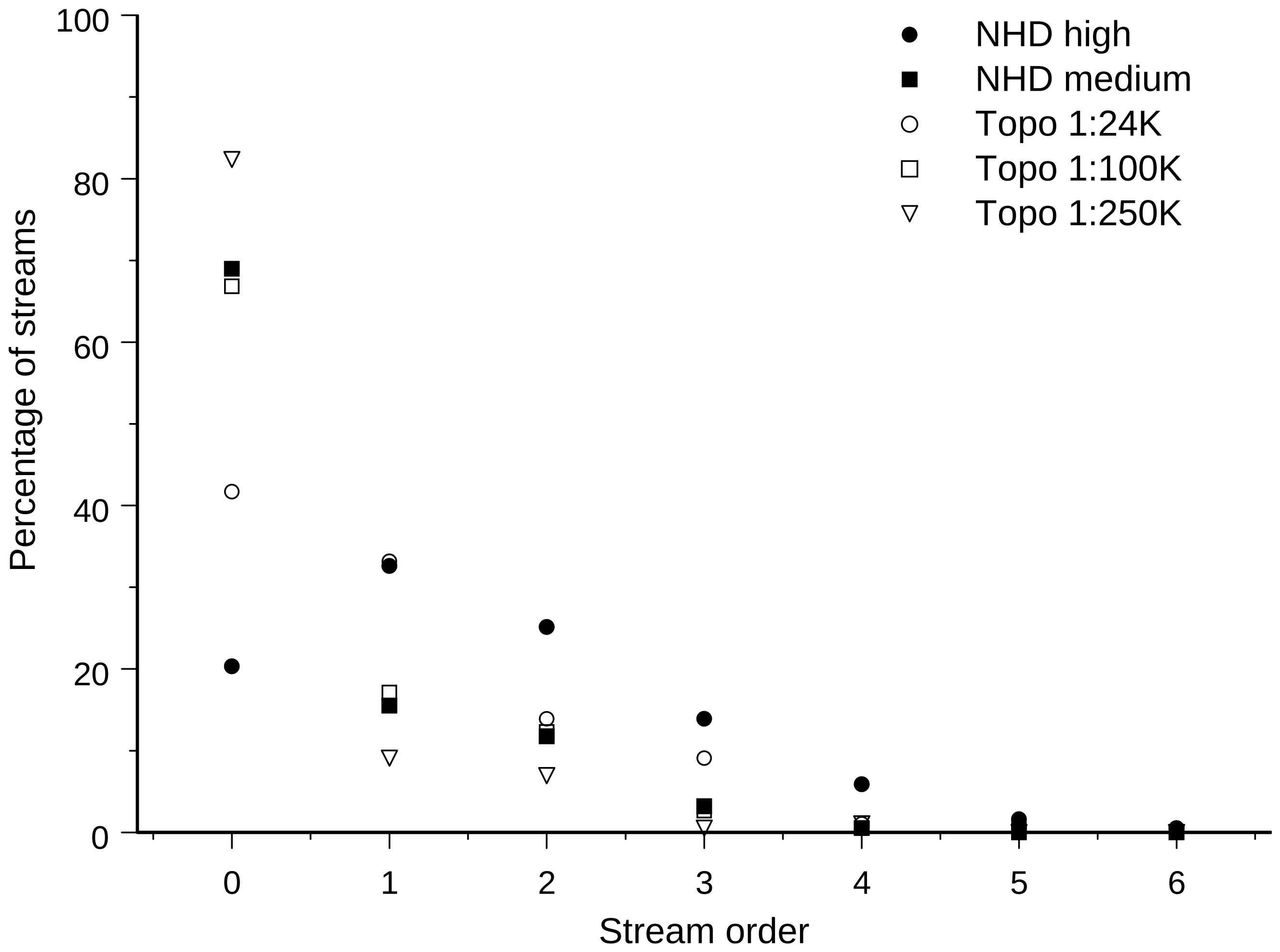
Number of reaches
60
40
20
0
-2 -1 0 1 2 3 4
60
40
20
0
-2 -1 0 1 2 3 4
Number of reaches
60
40
20
0
-2 -1 0 1 2 3 4
60
40
20
0
-2 -1 0 1 2 3 4
Difference in Strahler order
Number of reaches
60
40
20
0
-2 -1 0 1 2 3 4
Difference in Strahler order

Figure 4



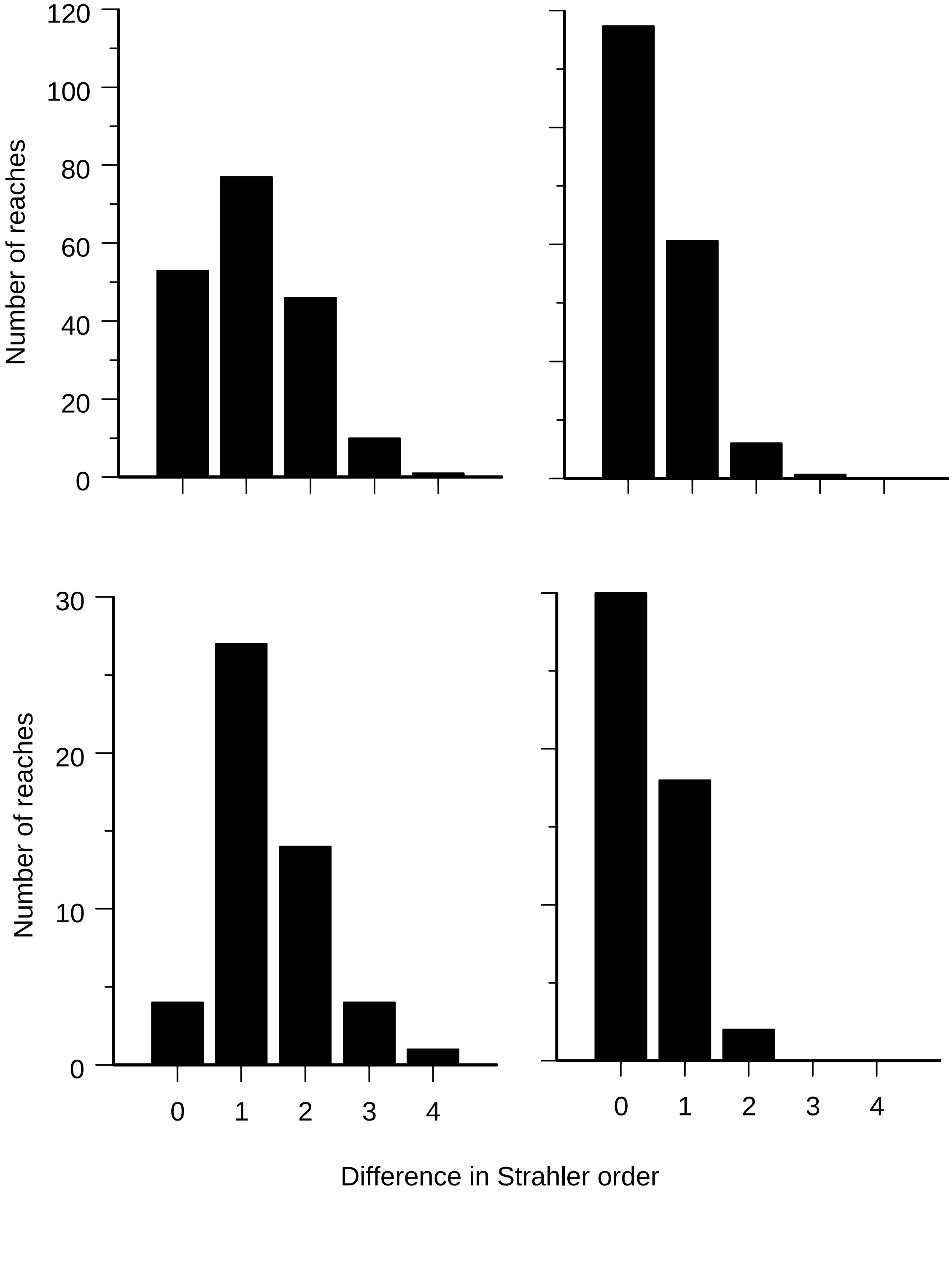
NHD high resolution
NHD med. resolution
Topo 1:24K
Topo 1:100K
NRCS
0
20
40
60
Generated

Figure 5.



NHD high
NHD medium
Topo 1:24K
Topo 1:100K
Topo 1:250K
Percentage of streams
Stream order
100
80
60
40
20
0
0
1
2
3
4
5
6

Figure 6.



120
100
80
60
40
20
0
Number of reaches
30
20
10
0
Number of reaches
0
1
2
3
4
0
1
2
3
4
Difference in Strahler order

Supplemental Table 1. Hydrogeographic resources used for comparisons.

Study Forest	Type	Reference
All	NHD_{24K}	http://nhd.usgs.gov
All	NHD_{100K}	http://nhd.usgs.gov
Indiana	$USGS_{24K}$	USGS. 1994. Story, IN quadrangle (N3900-W8607.5/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Revised 1967).
	$USGS_{24K}$	USGS. 1981. Elkinsville, IN quadrangle (N3900-W8615/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1947; Revised 1966).
	$USGS_{100K}$	USGS. 1990. Bloomington, IN (39086-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1986).
	NRCS	Thomas, J. A. 1981. Soil survey of Monroe County, Indiana. US Department of Agriculture, Natural Resource Conservation Service.
	NRCS	Nagel, B. G. 1990. Soil survey of Jackson County, Indiana. US Department of Agriculture, Natural Resource Conservation Service.
	NRCS	Noble, R.A., R.C. Wingard, Jr., and T.R. Ziegler. 1990. Soil survey of Brown and part of Bartholomew County, Indiana. US Department of Agriculture, Natural Resource Conservation Service.
	NRCS	Thomas, J. A. 1985. Soil survey of Lawrence County, Indiana. US Department of Agriculture, Natural Resource Conservation Service.
Kentucky	$USGS_{24}$	USGS. 1989. Noble, KY quadrangle (37083-D2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field check 1954; Photoinspected 1976).
	$USGS_{24}$	USGS. 1992. Vest, KY quadrangle (37083-D1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1990; Edited 1991).
	$USGS_{24}$	USGS. 1978. Guage, KY quadrangle (N3730-W8307.5/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1978).
	$USGS_{24}$	USGS. 1983. Tiptop, KY quadrangle (N3730-W8300/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1978).
	$USGS_{100}$	USGS. 1982. Irvine, KY (N3730-W8300/30X60). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1982).
	$USGS_{100}$	USGS. 1983 Hazzard, KY (373083-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1982).
	NRCS	Hayes, R.A. 1998. Soil survey of Breathitt County, Kentucky. US Department of Agriculture, Natural Resource Conservation Service.
SC Ohio	$USGS_{24}$	USGS. 1995. Concord, OH quadrangle (38083-F4-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1995).

	$USGS_{100}$	USGS. 1991. Maysville, OH (38083-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1991).
	NRCS	Lucht, T.E. and D.L. Brown. 1994. Soil survey of Adams County, Ohio. US Department of Agriculture, Natural Resource Conservation Service.
SE Ohio	$USGS_{24}$	USGS. 1977. Sherritts, OH quadrangle (N3837.5-W8230/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1961).
	$USGS_{24}$	USGS. 1989. Gallia, OH quadrangle (8082-G5-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1961).
	$USGS_{100}$	USGS. 1982. Ironton, OH (N3830-W8200/30X60). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1981).
	NRCS	NRCS. 1998. Soil survey of Lawrence County, Ohio. US Department of Agriculture, Natural Resource Conservation Service.
	NRCS	NRCS. 1997. Soil survey of Gallia County, Ohio. US Department of Agriculture, Natural Resource Conservation Service.
Illinois	$USGS_{24}$	USGS. 1962. Eddyville, IL quadrangle (N3730-W8830/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1961).
	$USGS_{24}$	USGS. 1988. Herod, IL quadrangle (37088-E4-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1959).
	$USGS_{100}$	USGS. 1987. West Frankfort, IL (37088-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1987).
	NRCS	Parks, W.D. 1975. Soil survey of Pope, Hardin, and Massac Counties, Illinois. US Department of Agriculture, Natural Resource Conservation Service.
New Hampshire	$USGS_{24}$	USGS. 1984. Lovewell Mountain, NH (43072-B1-TM-025). 1:25,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1980; Edited 1984).
	$USGS_{100}$	USGS. 1985. Claremont (43072-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1985).
	NRCS	Shook, R.A. 1983. Soil survey of Sullivan County, New Hampshire. US Department of Agriculture, Natural Resource Conservation Service.
Vermont	$USGS_{24}$	USGS. 1987. Hinesburg, VT (44073-C1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1948).
	$USGS_{100}$	USGS. 1989. Lake Champlain South (44073-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA. (Edited 1986, Photoinspected 1988).

	NRCS	Allen, G.W. 1974. Soil survey of Chittenden County, Vermont. US Department of Agriculture, Natural Resource Conservation Service.
Washington	$USGS_{24}$	USGS. 1986. Sun Top, WA (47121-AS-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1984; Edited 1986).
	$USGS_{100}$	USGS. 1975. Snoqualmie Pass, WA. 1:100,000 scale topographic map. US Department of Interior Reston, VA.
	NRCS	Goldin, A. 1992. Soil survey of Snoqualmie Pass area, Parts of King and Pierce Counties, Washington. US Department of Agriculture, Natural Resouces Conservation Service.
West Virginia	$USGS_{24}$	USGS. 1986. Lake Lynn, PA – WV (39079-F7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1960).
	$USGS_{24}$	USGS. 1978. Bruceton Mills, WV - PA (N3937-5-W7937.5/7.5). 1:24,000 scale topographic map. US Department of Interior Reston, VA. (Field checked 1960).
	$USGS_{100}$	USGS. 1983. Morgantown, WV – PA - MD. 1:100,000 scale topographic map. US Department of Interior Reston, VA (Edited 1978)
	NRCS	Wright, E.L., C. H. Delp, K. Sponaugle, C. Cole, J.T. Ammons, J. Gorman, and F. D. Childs. 1982. Soil survey of Marion and Monogalia Counties, West Virginia. US Department of Agriculture, Natural Resouces Conservation Service.
Oregon	$USGS_{24}$	USGS. 1977. Adel, OR (42119-B8-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1968).
	$USGS_{24}$	USGS. 1984. Airlie South, OR (44123-F3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1979).
	$USGS_{24}$	USGS. 1980. Alec Butte, OR (43119-C6-TF-024). 1:24,000 scale topographic map US Department of Interior Reston, VA (Field checked 1976).
	$USGS_{24}$	USGS. 1990. Alkali Flat, OR (44120-A6-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1986).
	$USGS_{24}$	USGS. 1975. Antelope Butte, OR (42119-A4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1971).
	$USGS_{24}$	USGS. 1984. Austin, OR (44118-E4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1983).
	$USGS_{24}$	USGS. 1988. Bates, OR (44118-E5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1985).
	$USGS_{24}$	USGS. 1988. Beatty, OR (42121-D3-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field

checked 1985).
USGS$_{24}$ USGS. 1986. Bedford Point, OR (44122-B2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
USGS$_{24}$ USGS. 1972. Blizzard Gap, OR (42119-A6-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1968).
USGS$_{24}$ USGS. 1993. Blue Canyon, OR (44117-F8-TF-024). 1:24,000 scale topographic map.US Department of Interior, Reston, VA (Field checked 1992).
USGS$_{24}$ USGS. 1986. Blue Mountain, OR (43122-F8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1988. Bowman Dam, OR (44120-A7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1986).
USGS$_{24}$ USGS. 1979. Brothers NW, OR (43120-H6-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1967).
USGS$_{24}$ USGS. 1988. Brownsville, OR (44122-D8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1990. Cadle Butte, OR (44120-C5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1986).
USGS$_{24}$ USGS. 1984. Canyon Mtn., OR (44118-C8-TF-024). 1:24,000 scale topographic map.US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1983).
USGS$_{24}$ USGS. 1987. Corvallis, OR (44123-E3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1969, Photorevised 1986).
USGS$_{24}$ USGS. 1987. Cottage Grove Lake, OR (43123-F1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
USGS$_{24}$ USGS. 1988. Crawfordsville, OR (44122-C7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1987. Curtin, OR (43123-F2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
USGS$_{24}$ USGS. 1990. Dale, OR (44119-H8-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).
USGS$_{24}$ USGS. 1987. Dallas, OR (44123-H3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1974, Photorevised 1986).

$USGS_{24}$	USGS. 1990. Devine Ridge North, OR (43118-G8-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1985-86).
$USGS_{24}$	USGS. 1993. Dooley Mtn., OR (44117-E7-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1992).
$USGS_{24}$	USGS. 1986. Dorena Lake, OR (43122-G8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
$USGS_{24}$	USGS. 1990. Drewsey, OR (43118-G4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).
$USGS_{24}$	USGS. 1985. Echo Mountain, OR (44122-D1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1981).
$USGS_{24}$	USGS. 1985. Elkhorn, OR (44122-G3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1982).
$USGS_{24}$	USGS. 1977. Fall City, OR (44123-G4-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1974).
$USGS_{24}$	USGS. 1974. Fields Basin, OR (42118-C7-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1971).
$USGS_{24}$	USGS. 1986. Fish Creek Mtn., OR (45122-A1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
$USGS_{24}$	USGS. 1984. Fox Hollow, OR (43123-H2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1981).
$USGS_{24}$	USGS. 1978. Frenchglen, OR (42118-G8-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA.
$USGS_{24}$	USGS. 1980. Greenberry, OR (44123-D3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1969, Photoinspected 1975).
$USGS_{24}$	USGS. 1985. Greenhorn, OR (44118-F4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1984).
$USGS_{24}$	USGS. 1971. Halsey, OR (44123-D1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1969).
$USGS_{24}$	USGS. 1985. Harter Mtn., OR (44122-D2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1981).
$USGS_{24}$	USGS. 1981. Hat Butte, OR (43119-E8-TF-024). 1:24,000 scale topographic map US Department of Interior Reston, VA (Field

checked 1977).
USGS$_{24}$ USGS. 1984. Horton, OR (44123-B4-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1980).
USGS$_{24}$ USGS. 1986. Jasper, OR (43122-H8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1990. Johnson Saddle, OR (44119-E1-TF-024) 1:24,000 scale US Department of Interior, Reston, VA (Field checked 1987).
USGS$_{24}$ USGS. 1972. Keeney Ridge, OR (43117-F5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972).
USGS$_{24}$ USGS. 1985. Lawhead Creek, OR (44122-F3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1982).
USGS$_{24}$ USGS. 1985. Lawson Mtn., OR (44120-E3-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1968, Photorevised 1985).
USGS$_{24}$ USGS. 1984. Lehman Springs, OR (45118-B6-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1967, Photorevised 1983).
USGS$_{24}$ USGS. 1984. Lorane, OR (43123-G2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1980).
USGS$_{24}$ USGS. 1994. Marion Forks, OR (44121-E8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1985. Marley Creek, OR (45118-B4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1965, Photorevised 1984).
USGS$_{24}$ USGS. 1986. McCredie Springs, OR (43122-F3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
USGS$_{24}$ USGS. 1979. Midway, OR (45123-A6-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1974).
USGS$_{24}$ USGS. 1993. Mission Bottom, OR (45123-A1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1987).
USGS$_{24}$ USGS. 1990. Mosquito Flat, OR (43119-G1-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1986).
USGS$_{24}$ USGS. 1994. Mt. Bruno, OR (44121-F8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).
USGS$_{24}$ USGS. 1986. Mt. David Douglas, OR (43122-F2-TF-024).

1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).

USGS$_{24}$ USGS. 1986. Mount June, OR (43122-G6-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).

USGS$_{24}$ USGS. 1990. Namorf, OR (43117-G6-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).

USGS$_{24}$ USGS. 1995. Neskowin, OR (45123-A8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1982).

USGS$_{24}$ USGS. 1985. Newberg, OR (45122-C8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1961, Photorevised 1985).

USGS$_{24}$ USGS. 1986. Oakridge, OR (43122-F4-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).

USGS$_{24}$ USGS. 1977. Peoria, OR (44123-D2-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1969, Photoinspected 1975).

USGS$_{24}$ USGS. 1990. Petes Mountain, OR (43118-G2-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).

USGS$_{24}$ USGS. 1985. Phillips Lake, OR (44118-F1-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1984).

USGS$_{24}$ USGS. 1971. Piute Reservoir, OR (42119-A5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1968).

USGS$_{24}$ USGS. 1985. Pogue Point, OR (44118-E3-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1984).

USGS$_{24}$ USGS. 1990. Poison Creek, OR (43119-F1-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).

USGS. 1988. Quartz Valley, OR (42120-C7-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1984).

USGS$_{24}$ USGS. 1972. Roaring Springs, OR (42118-F8-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1967).

USGS$_{24}$ USGS. 1986. Saddleblanket Mtn., OR (43122-H5-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).

USGS$_{24}$ USGS. 1972. Sage Hen Butte, OR (42120-B1-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA

(Field checked 1968).

$USGS_{24}$ USGS. 1977. Sage Hen Hills, NV/OR (41119-H3-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1966).

$USGS_{24}$ USGS. 1995. Saint Helens, OR/WA (45122-G7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1990).

$USGS_{24}$ USGS. 1985. St. Paul, OR (45122-B8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1985).

$USGS_{24}$ USGS. 1995. Sauvie Island (45122-F7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1990).

$USGS_{24}$ USGS. 1990 South Mountain, OR (43117-G7-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).

$USGS_{24}$ USGS. 1992. Springfield, OR (44122-A8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1967, Photorevised 1986).

$USGS_{24}$ USGS. 1988. Stearns Butte, OR (44120-B7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1986).

$USGS_{24}$ USGS. 1985. Stephenson Mtn., OR (44120-E4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1968, Photorevised 1985).

$USGS_{24}$ USGS. 1978. Stinkingwater Pass, OR (43118-F5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1973).

$USGS_{24}$ USGS. 1982. Suntex, OR (43119-E6-TF-024). 1:24,000 scale topographic map US Department of Interior Reston, VA (Field checked 1977).

$USGS_{24}$ USGS. 1989. Tamolitch Falls., OR (44122-C1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).

$USGS_{24}$ USGS. 1987. Tangent, OR (44123-E1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1969, Photorevised 1986).

$USGS_{24}$ USGS. 1988. Three Fingered Jack, OR (44121-D7-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1985).

$USGS_{24}$ USGS. 1981. Tumtum Lake, OR (42118-B5-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1977).

$USGS_{24}$ USGS. 1988. Union Point, OR (44122-C8-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1984).

$USGS_{24}$	USGS. 1985. Unity, OR (44118-D2-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1984).
$USGS_{24}$	USGS. 1985. Upper Soda, OR (44122-D3-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1982).
$USGS_{24}$	USGS. 1986. Westfir West, OR (43122-G5-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1983).
$USGS_{24}$	USGS. 1990. Whistler Point, OR (44120-D4-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1986).
$USGS_{24}$	USGS. 1990. Whitetail Butte, OR (44119-H6-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1987).
$USGS_{24}$	USGS. 1985. Whitney, OR (44118-F3-TF-024). 1:24,000 scale topographic map. US Department of Interior, Reston, VA (Field checked 1972, Photorevised 1984).
$USGS_{24}$	USGS. 1986. Willamette Pass, OR (43122-E1-TF-024). 1:24,000 scale topographic map. US Department of Interior Reston, VA (Field checked 1985).
$USGS_{100}$	USGS. 1994. Adel, OR (42119-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1991).
$USGS_{100}$	USGS. 1982. Alvord Lake, OR (42118-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1979).
$USGS_{100}$	USGS. 1981. Baker, OR/ID (44117-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1975-77).
$USGS_{100}$	USGS. 1987. Bates, OR (44118-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1981).
$USGS_{100}$	USGS. 1980. Bend, OR (44121-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photoinspected 1991).
$USGS_{100}$	USGS. 1983. Brothers, OR (43120-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photoinspected 1991).
$USGS_{100}$	USGS. 1993. Burns, OR (43119-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1984).
$USGS_{100}$	USGS. 1981. Corvallis, OR (44123-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1975-76).
$USGS_{100}$	USGS. 1979. Cottage Grove, OR (43123-E1-TM-100). 1:100,000

scale topographic map. US Department of Interior Reston, VA (Photorevised 1974-75).

$USGS_{100}$ USGS. 1980. Eugene, OR (44123-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1975).

$USGS_{100}$ USGS. 1994. Harney Lake, OR (43119-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1989-90).

$USGS_{100}$ USGS 1978. John Day, OR (44118-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1975).

$USGS_{100}$ USGS. 1991. Klamath Falls, OR/CA (42121-A1-TF-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA.

$USGS_{100}$ USGS. 1979. La Grande, OR (45118-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1976).

$USGS_{100}$ USGS. 1975. Lakeview, OR (42120-A1-TM-100). 1:100,000 scale topographic map US Department of Interior, Reston, VA (Photorevised 1990).

$USGS_{100}$ USGS. 1983. Madras, OR (44121-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1975).

$USGS_{100}$ USGS. 1983. McKenzie River, OR (44122-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1973).

$USGS_{100}$ USGS 1980. Monument, OR (44119-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1975).

$USGS_{100}$ USGS. 1983. North Santiam, OR (44122-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1975).

$USGS_{100}$ USGS. 1983. Oakridge, OR (43122-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1973-74).

$USGS_{100}$ USGS. 1983. Oregon City, OR (45122-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1981).

$USGS_{100}$ USGS. 1981. Prineville, OR (44120-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1978).

$USGS_{100}$ USGS. 1982. Steens Mtn., OR (42118-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1979).

$USGS_{100}$ USGS. 1981. Stephenson Mountain, OR (44120-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior

Reston, VA (Photorevised 1978).
USGS$_{100}$ USGS. 1978. Stinkingwater Mountains, OR (43118-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1974).
USGS$_{100}$ USGS. 1993. Vale, OR/ID (43117-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1987-88).
USGS$_{100}$ USGS. 1979. Vancouver, WA/OR (45122-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1975).
USGS$_{100}$ USGS. 1987. Vya, OR (41119-E1-TM-100). 1:100,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1980).
USGS$_{100}$ USGS. 1980. Yamhill River, OR (45123-A1-TM-100). 1:100,000 scale topographic map. US Department of Interior Reston, VA (Photorevised 1976-77).
USGS$_{250}$ USGS. 1976. Adel, OR (42118-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).
USGS$_{250}$ USGS. 1976. Baker, OR/ID (44116-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1974).
USGS$_{250}$ USGS. 1973. Bend, OR (44120-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1971).
USGS$_{250}$ USGS. 1977. Boise, ID/OR (43116-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1976).
USGS$_{250}$ USGS. 1972. Burns, OR (43118-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).
USGS$_{250}$ USGS. 1981. Canyon City, OR (44118-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).
USGS$_{250}$ USGS. 1973. Cresent, OR (43120-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).
USGS$_{250}$ USGS. 1972. Klamath Falls, OR/CA (42120-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).
USGS$_{250}$ USGS. 1980. Pendleton, OR/WA (45118-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Photorevised 1973).
USGS$_{250}$ USGS. 1973. Roseburg, OR (43122-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).

$USGS_{250}$	USGS. 1978. Salem, OR (44122-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1977).
$USGS_{250}$	USGS. 1976. Vancouver, WA/OR (45122-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1974).
$USGS_{250}$	USGS. 1973. Vya, NV/OR/CA (41118-A1-TF-250). 1:250,000 scale topographic map. US Department of Interior, Reston, VA (Revised 1970).