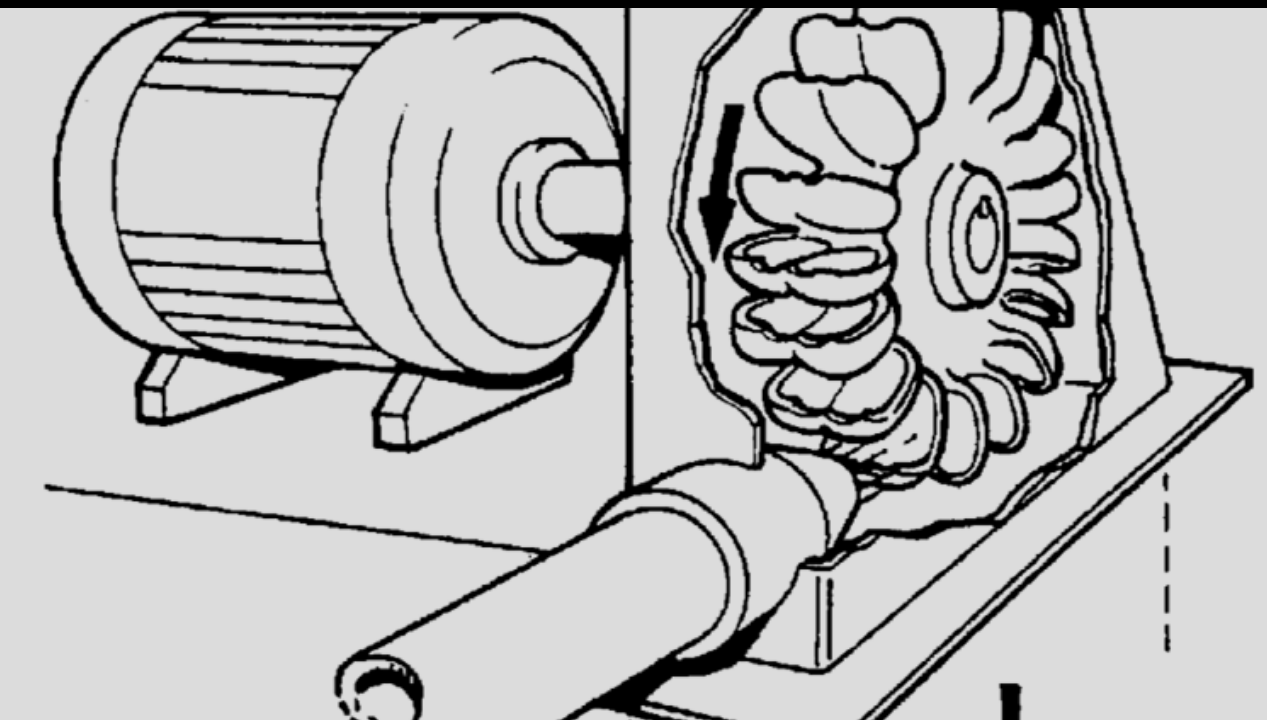
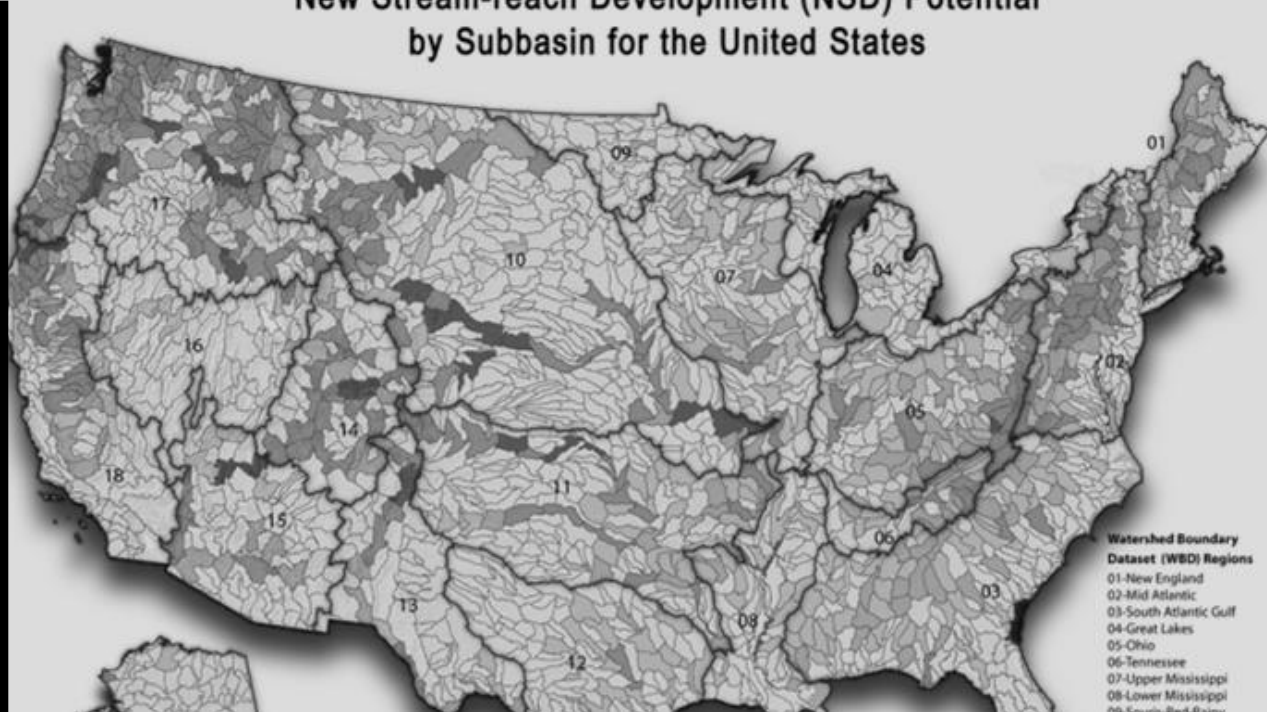
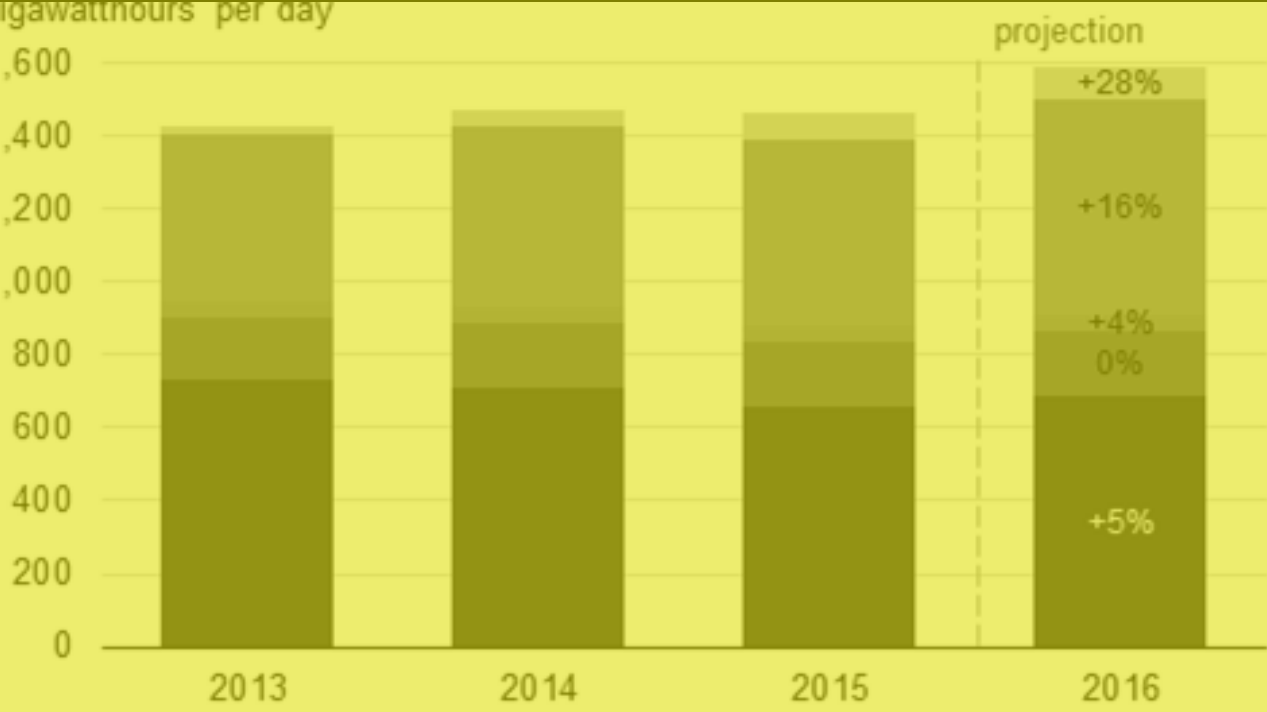


A brief look at run-of-river hydroelectric plants in the U.S.

HYDROPOWER



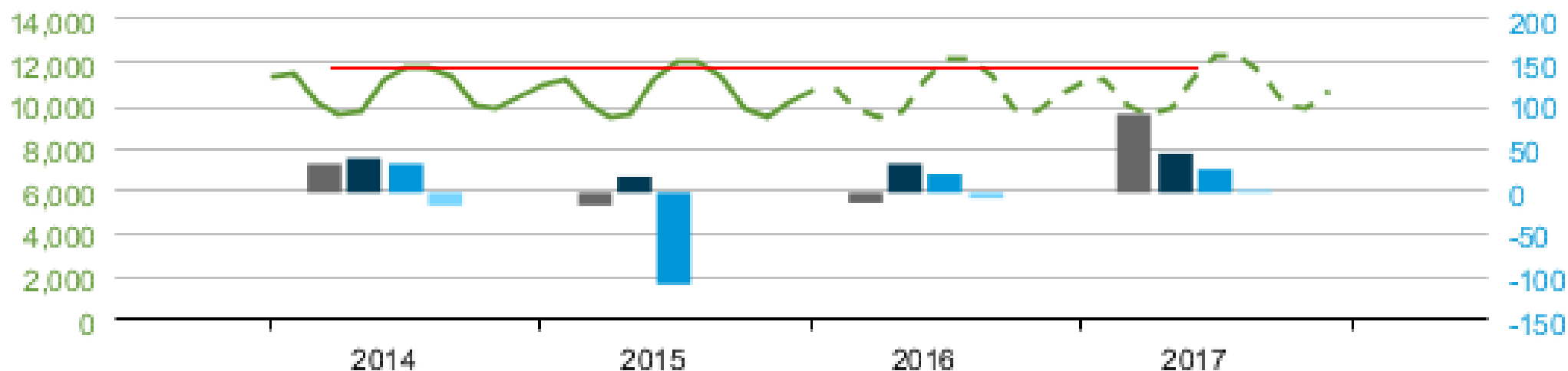


$$\frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

U.S. Electricity Consumption

(million kilowatthours per day)

(year over year change, million kilowatthours per day)



- Total consumption (left axis)
- - Consumption forecast (left axis)
- Residential (right axis)
- Commercial and transportation (right axis)
- Industrial (right axis)
- Direct use (right axis)

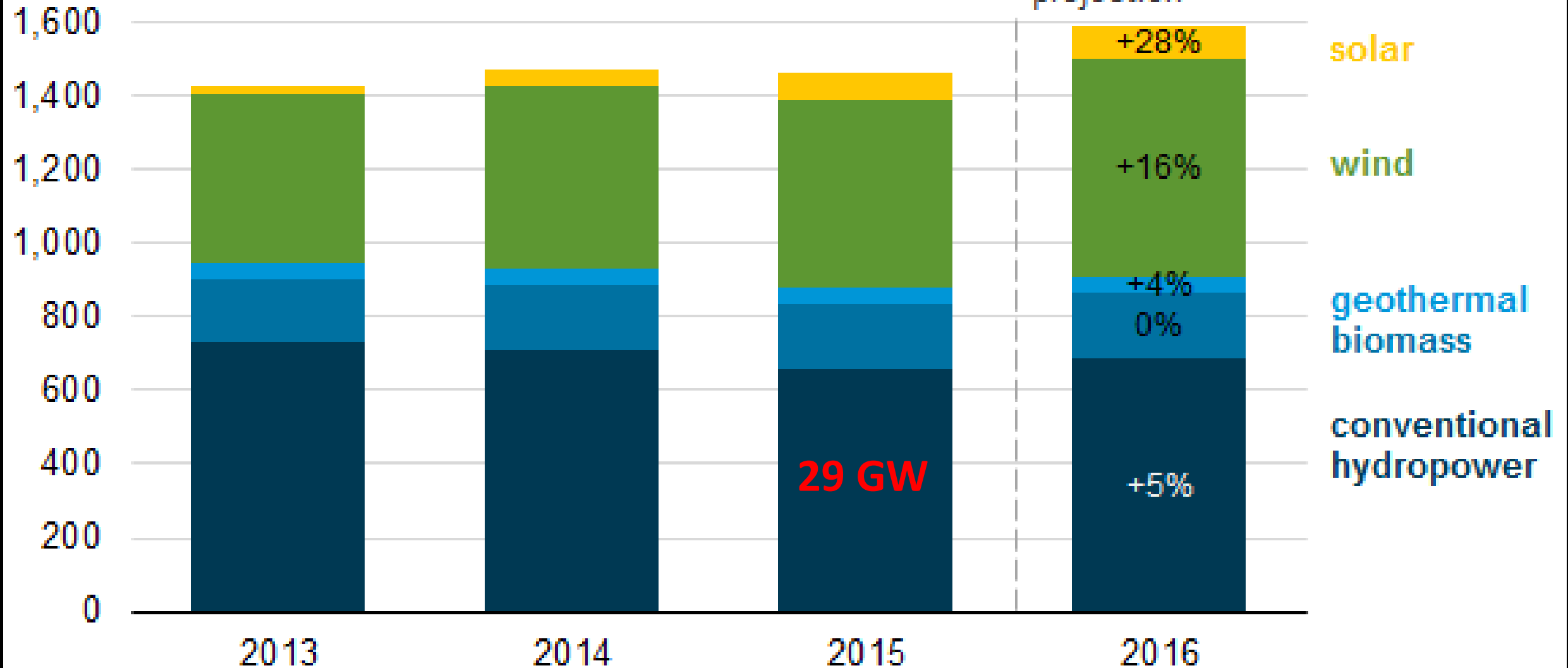


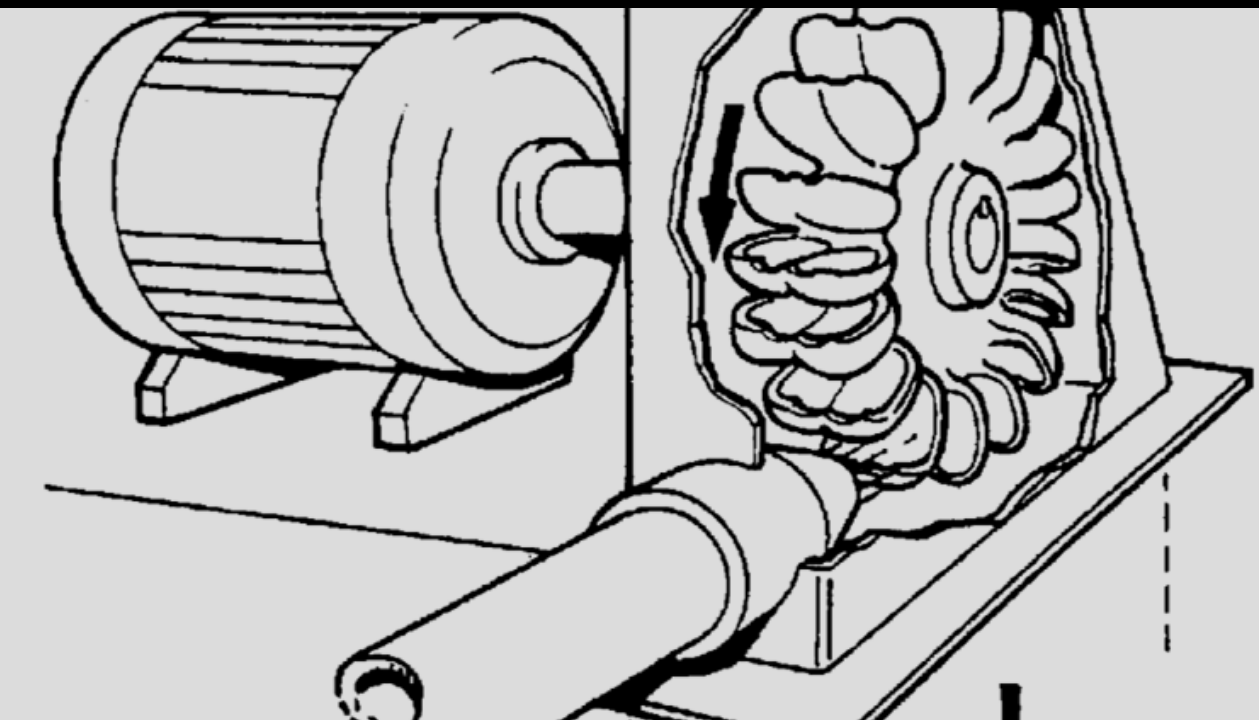
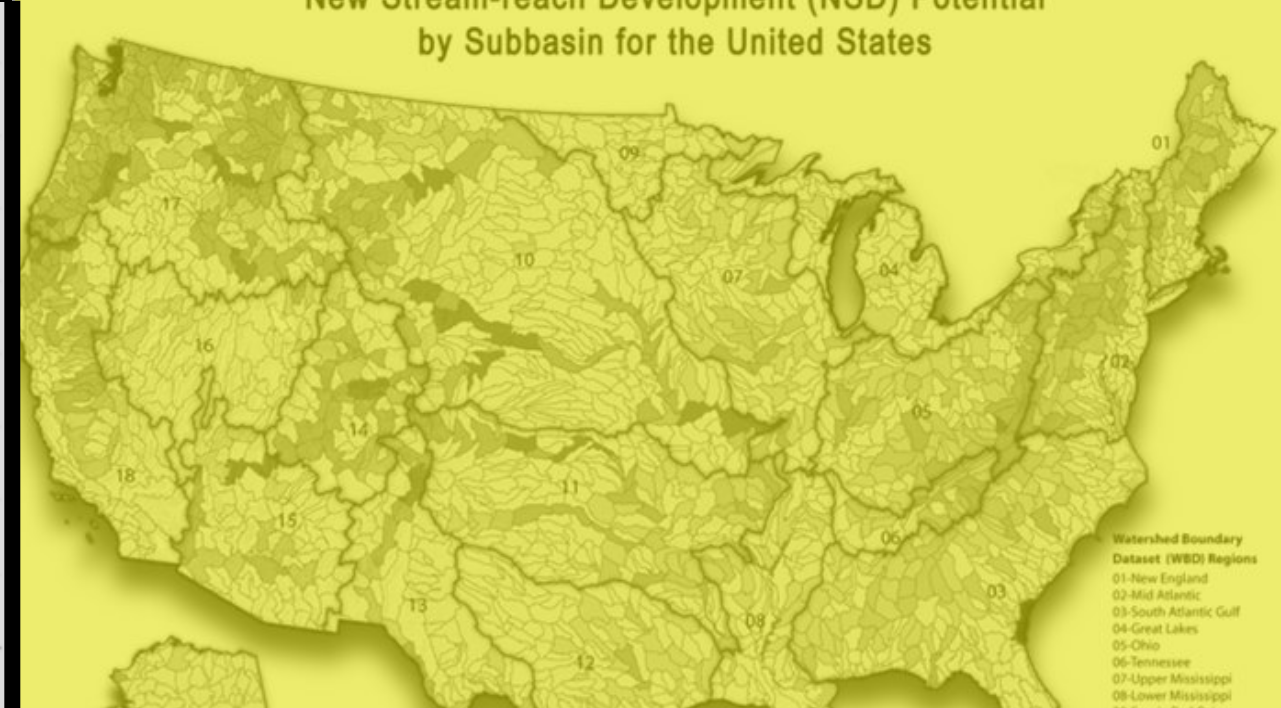
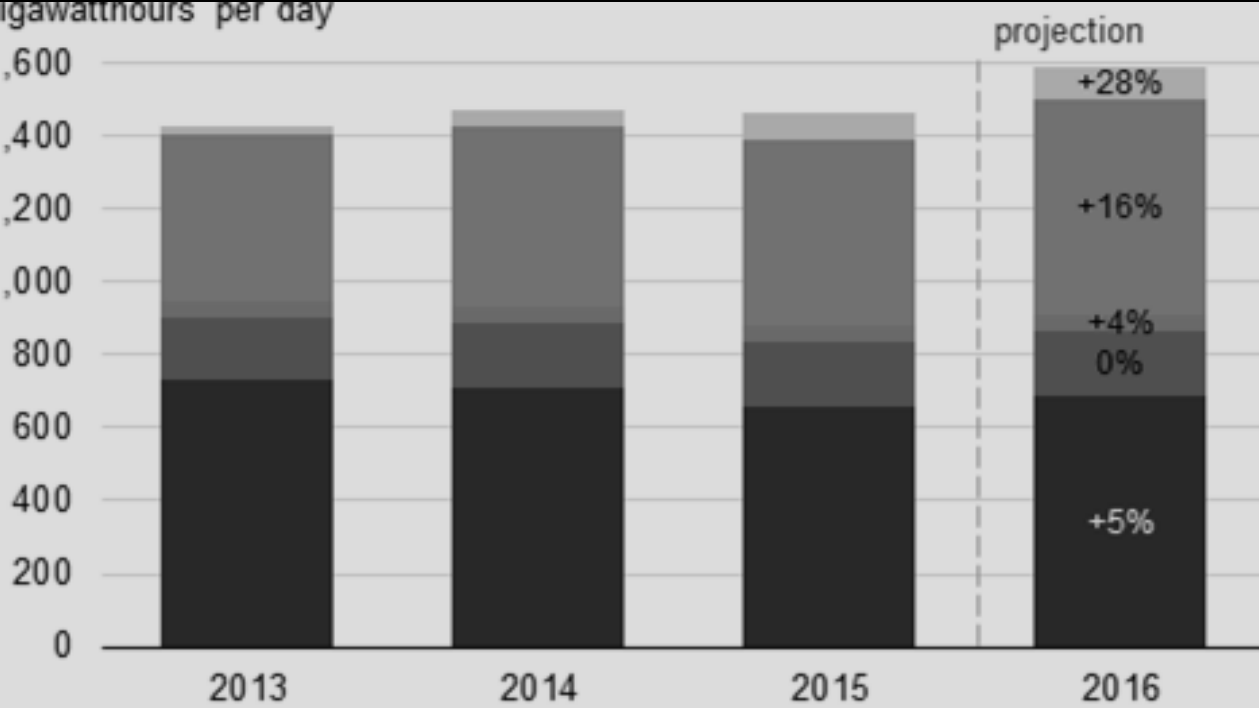
Source: Short-Term Energy Outlook, February 2016

Electricity generation from utility-scale plants, 2013-16



gigawatthours per day





$$\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}$$

$$\sum_{t=1}^n \frac{E_t}{(1+r)^t}$$



Energy Efficiency &
Renewable Energy

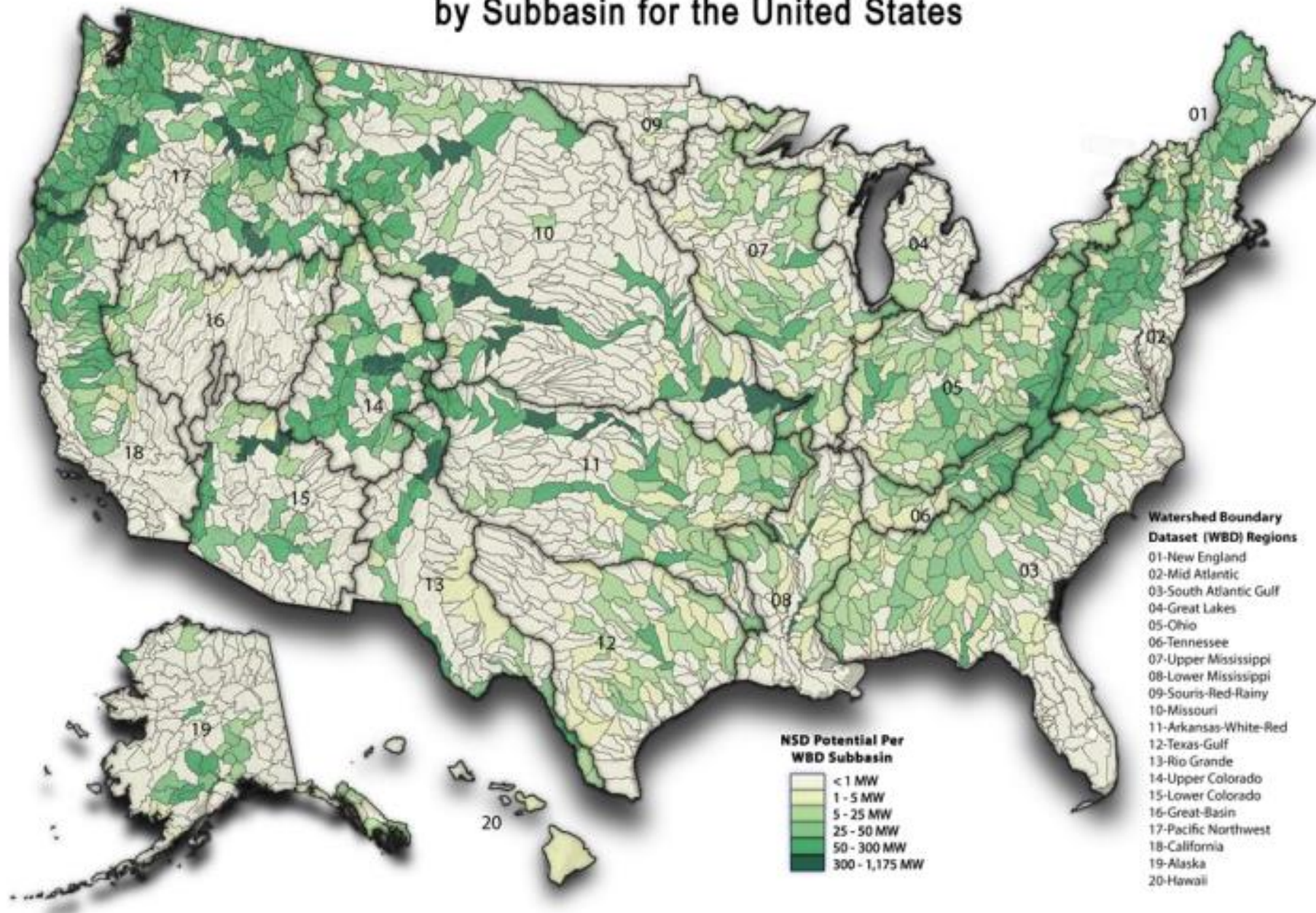
WIND & WATER POWER TECHNOLOGIES OFFICE

New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States

Shih-Chieh Kao, Principal Investigator

Ryan A. McManamay, Kevin M. Stewart, Nicole M. Samu, Boualem Hadjerioua, Scott T. DeNeale, Dilruba Yeasmin, M. Fayzul K. Pasha, Abdoul A. Oubeidillah, and Brennan T. Smith

New Stream-reach Development (NSD) Potential by Subbasin for the United States



Laboratory with evaluating the new s
of **more than 3 million U.S. streams** in
the feasibility of developing new hydr

o **natural ecological systems; sensitive species; areas of social and cultural
importance; and policy, management, and legal constraints.**

new stream-reach development is 84.7 GW

estimated NSD capacity falls to **65.5 GW,**

1. Identify energy dense stream-reaches

2. Perform topographical analysis of inundation potential

2. Attach energy potential information with natural ecological systems; social and cultural settings; and policies, management, and legal constraints

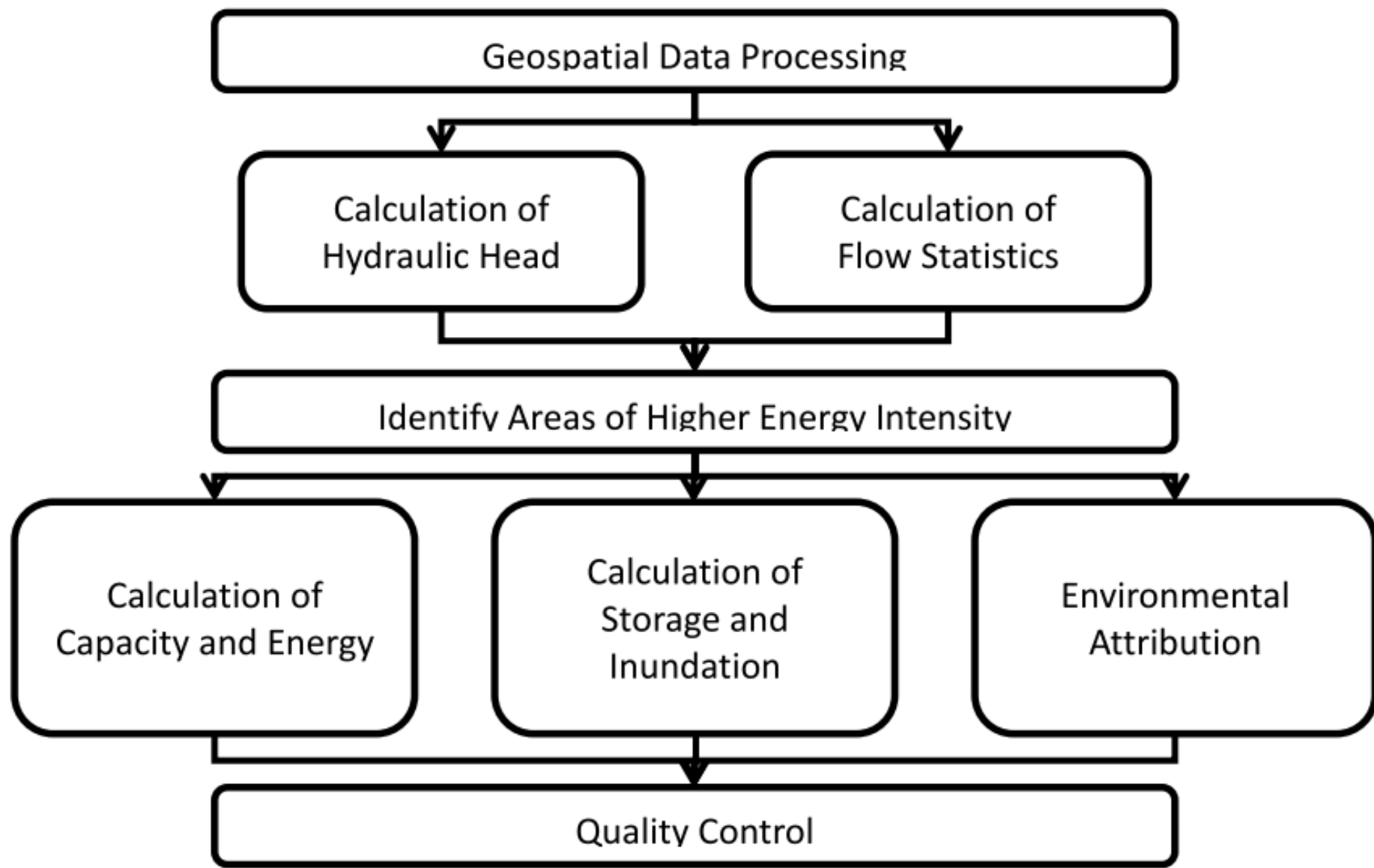
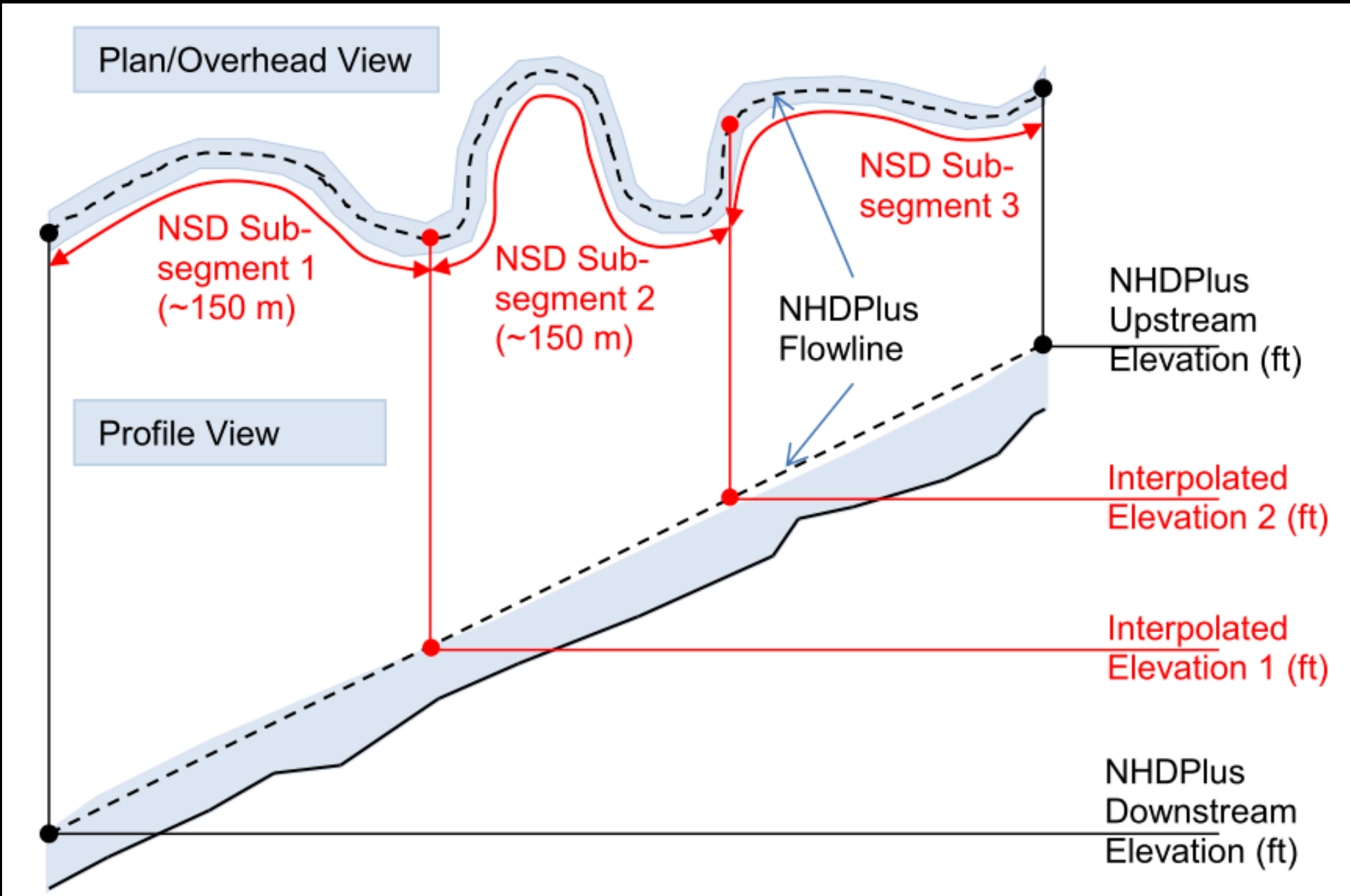


Figure 2.1. General steps of the NSD methodology.



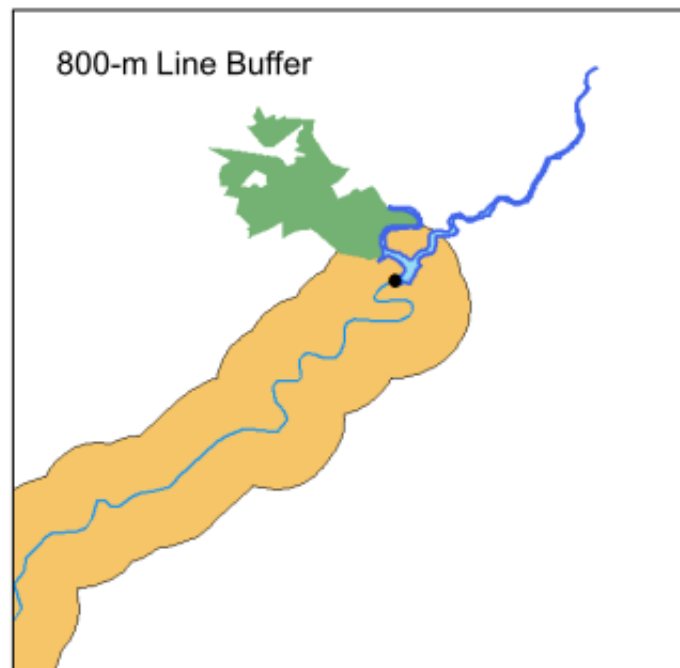
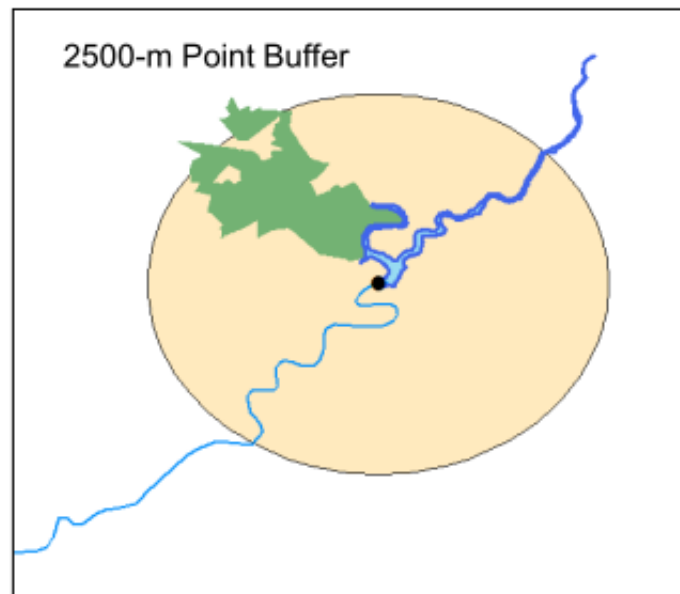
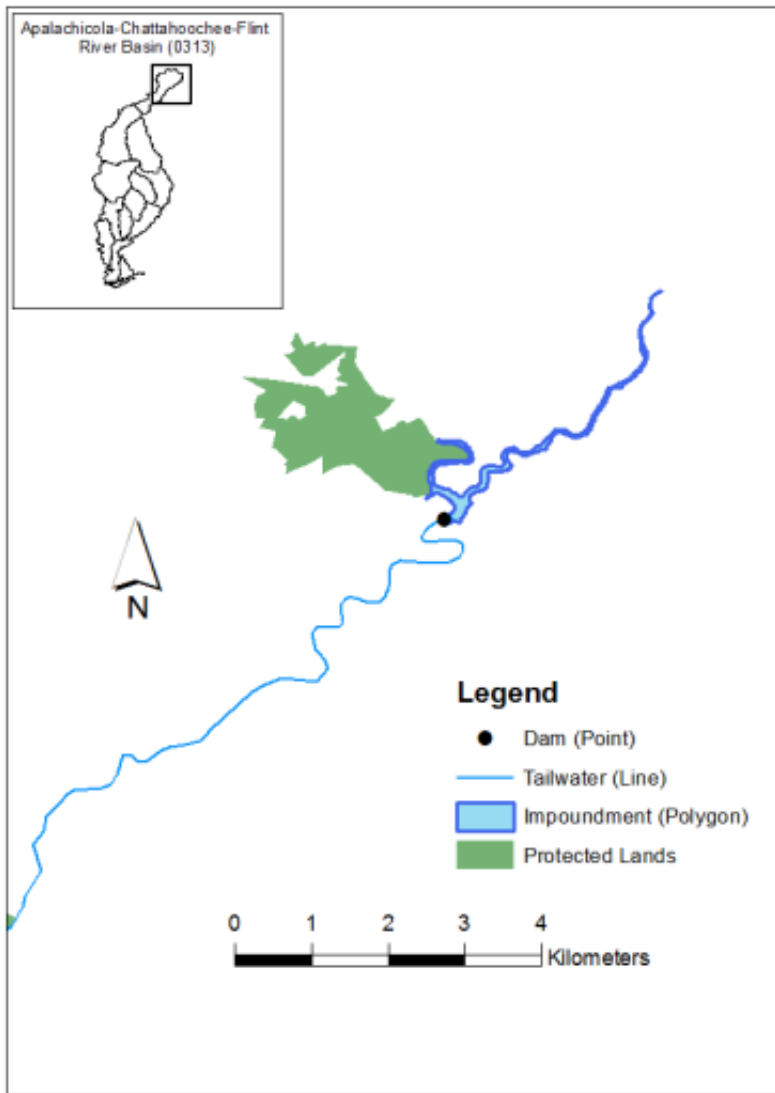
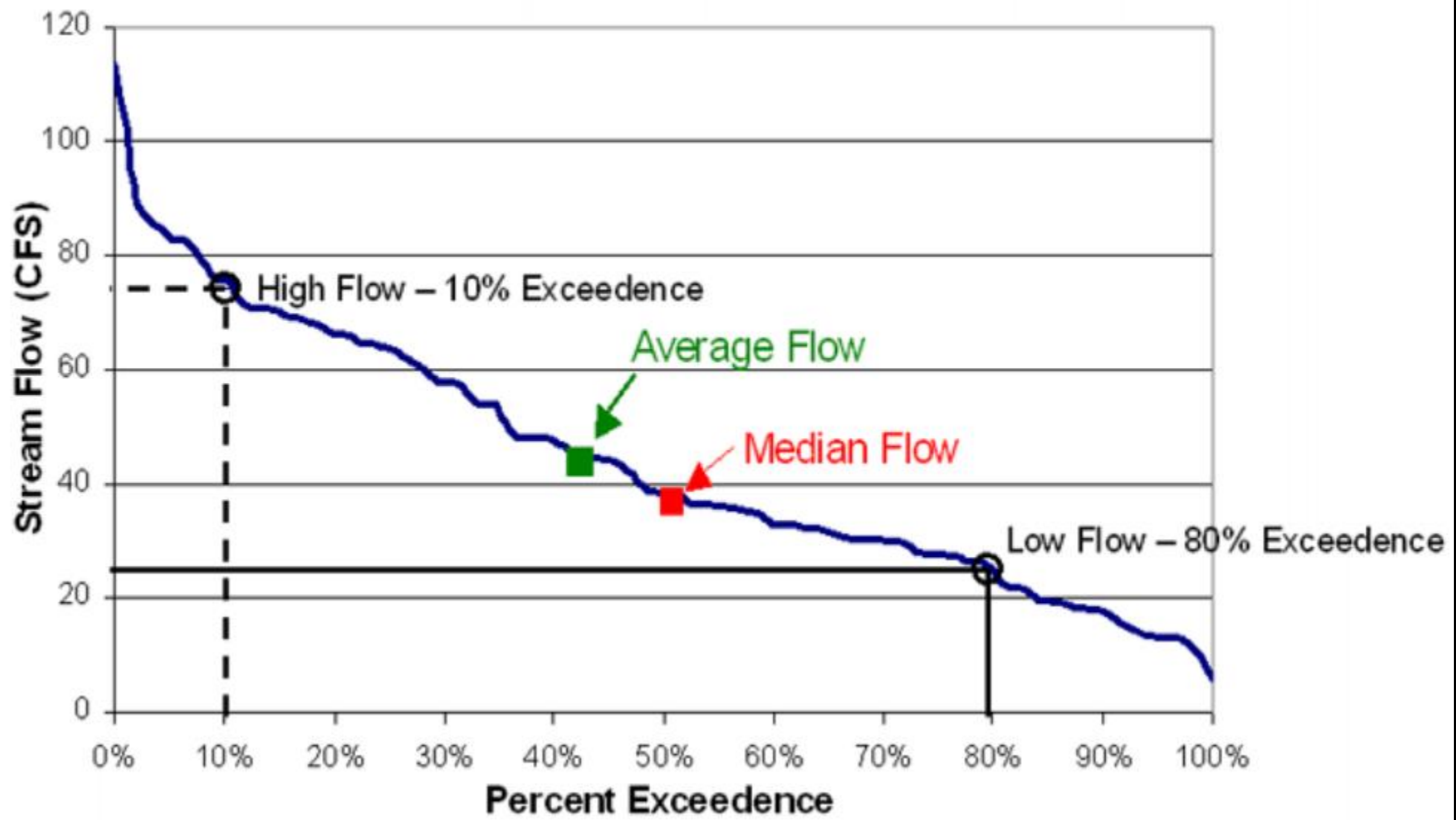


Table 2.3. Variable Buffer Widths According to Different Data Layers and Different Site Elements (Points, Lines, and Polygons)

Category	Data layer	Buffer width (m)		
		Point	Line	Polygon
Critical habitat	Critical habitats	8,000	800	800
Land ownership	Land owner (agency)	2,500	800	800
Land ownership	Land designation	2,500	800	800
Land ownership	Land conservation status	2,500	800	800
Water quality	303d waterbodies	500	500	500
Recreation	Fishing access/boat ramp	500	500	500
Recreation	Kayak/rafting access	500	500	500
Recreation	Waterfalls	2,500	800	800



$$P_{NSD} = c * \gamma * \eta * H_{ref} * Q_{30}$$

$$E_{NSD,m} = \begin{cases} c * \gamma * \eta * H_{ref} * (Q_{30} * T_m), & Q_{WW,m} > Q_{30} \\ c * \gamma * \eta * H_{ref} * (Q_{WW,m} * T_m), & 0 \leq Q_{WW,m} \leq Q_{30} \end{cases}$$

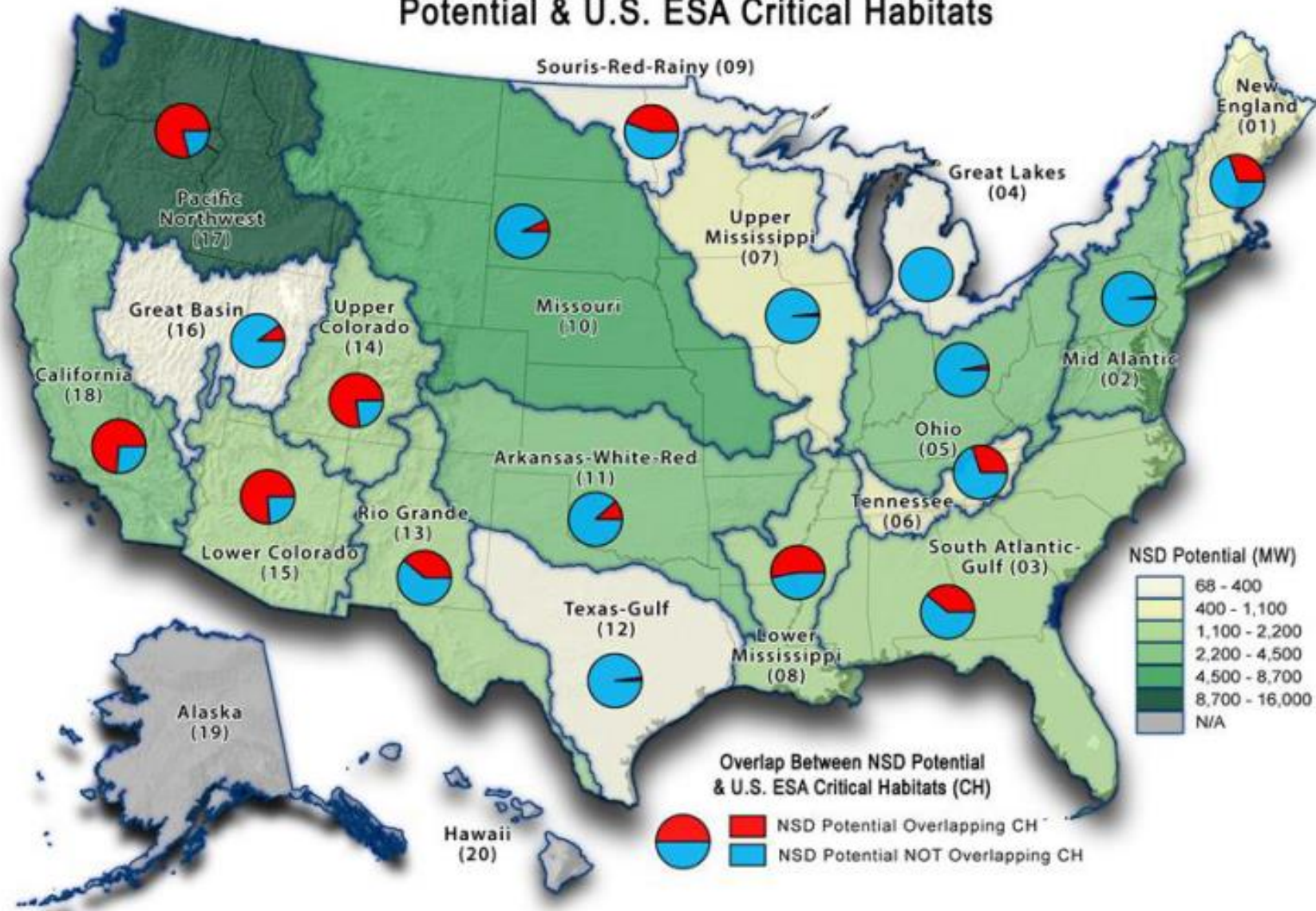
Table ES.2. Summary of NSD Findings by States

State	Potential capacity (MW)	Potential generation (MWh/year)	State	Potential capacity (MW)	Potential generation (MWh/year)
AK*	4,723	(not estimated)	MT	4,763	28,201,000
AL	663	3,522,000	NC	857	5,067,000
AR	1,253	6,685,000	ND	252	1,524,000
AZ	2,484	1,5459,000	NE	1,942	11,917,000
CA	6,983	3,7564,000	NH	407	2,410,000
CO	4,295	2,5623,000	NJ	171	1,006,000
CT	151	865,000	NM	1,280	7,193,000
DE	6	35,000	NV	232	1,245,000
FL	170	956,000	NY	1,900	10,715,000
GA	621	3,604,000	OH	535	2,800,000
HI*	145	699,000	OK	1,147	5,838,000
IA	736	3,869,000	OR	8,920	53,353,000
ID	7,018	41,015,000	PA	2,889	15,795,000
IL	599	3,241,000	RI	13	71,000
IN	581	3,123,000	SC	309	1,844,000
KS	2,479	14,931,000	SD	230	1,363,000
KY	675	3,301,000	TN	1,002	5,618,000
LA	790	4,463,000	TX	1,580	8,089,000
MA	194	1,114,000	UT	1,376	8,246,000
MD	223	1,212,000	VA	1,234	6,869,000
ME	1,132	6,532,000	VT	401	2,344,000
MI	449	2,866,000	WA	7,381	43,788,000
MN	568	3,191,000	WI	556	3,513,000
MO	2,512	14,514,000	WV	1,851	9,910,000
MS	1,129	6,449,000	WY	2,960	10,776,000

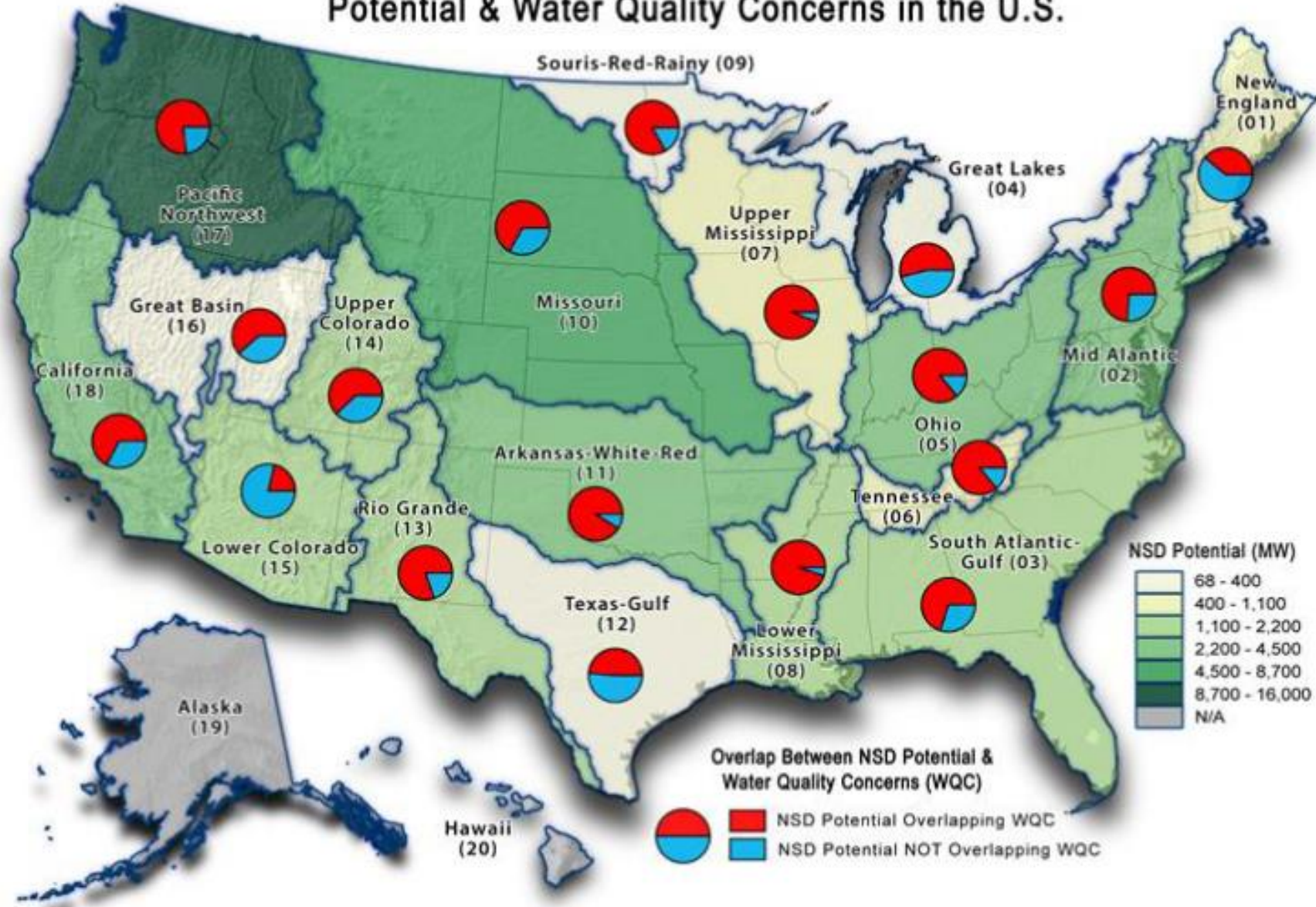
* The AK and HI potential are estimated by a different approach from that used for the other 48 states.

Information required to characterize and analyze each are produced. Information is preferred at the scale of the entire country or conterminous United States. Internet searches are also conducted through USGS, NatureServe, National Fish Habitat Action Plan (NFHAP), U.S. Census Bureau, USACE NID, U.S. Fish and Wildlife, Geology.com, EPA, National Wild and Scenic Rivers, National Atlas, and other webpages, including Google® searches. Potential issues to be characterized and attributed are finalized on the basis of information priority level and

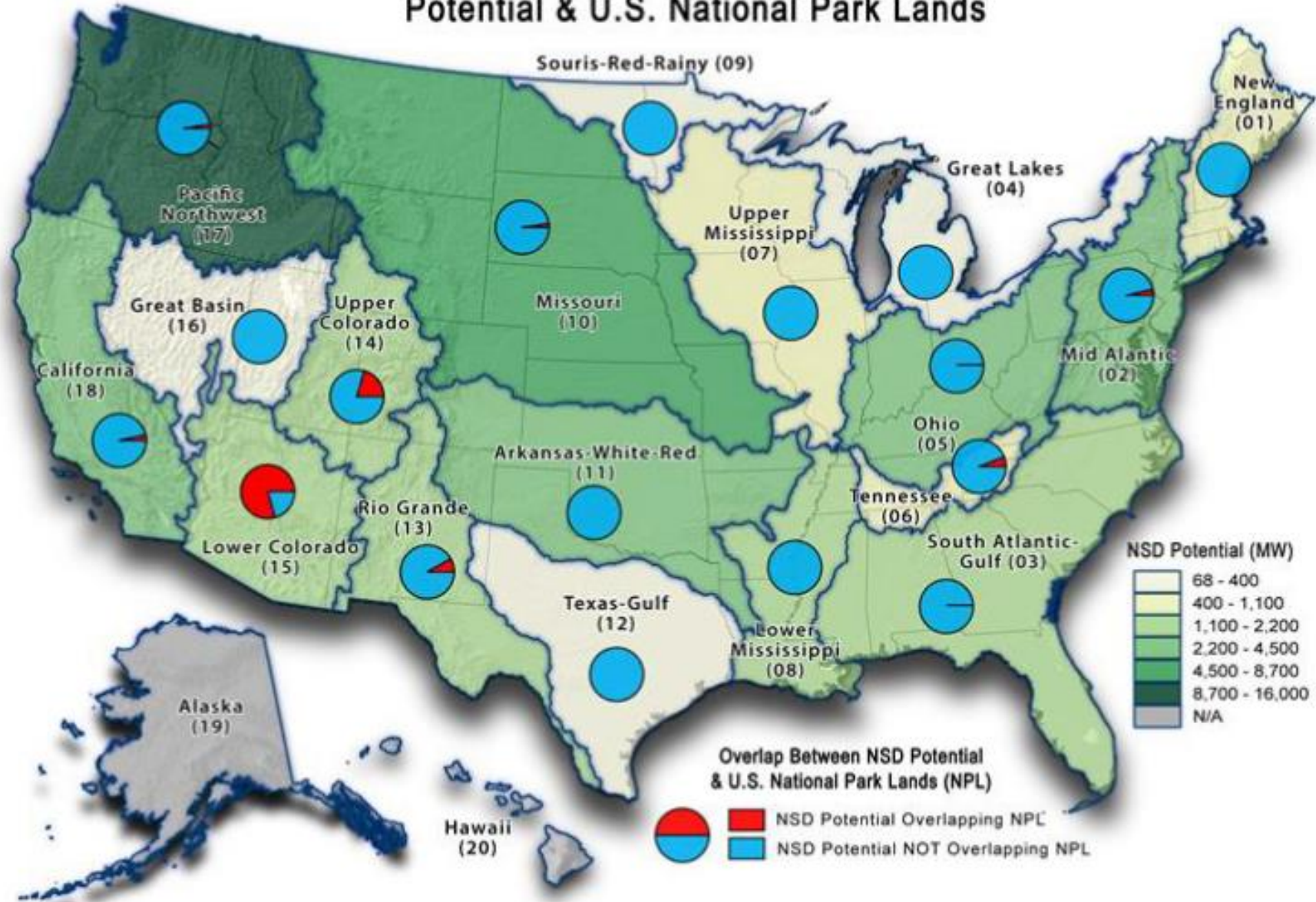
Overlap By Region Between New Stream-reach Development (NSD) Potential & U.S. ESA Critical Habitats



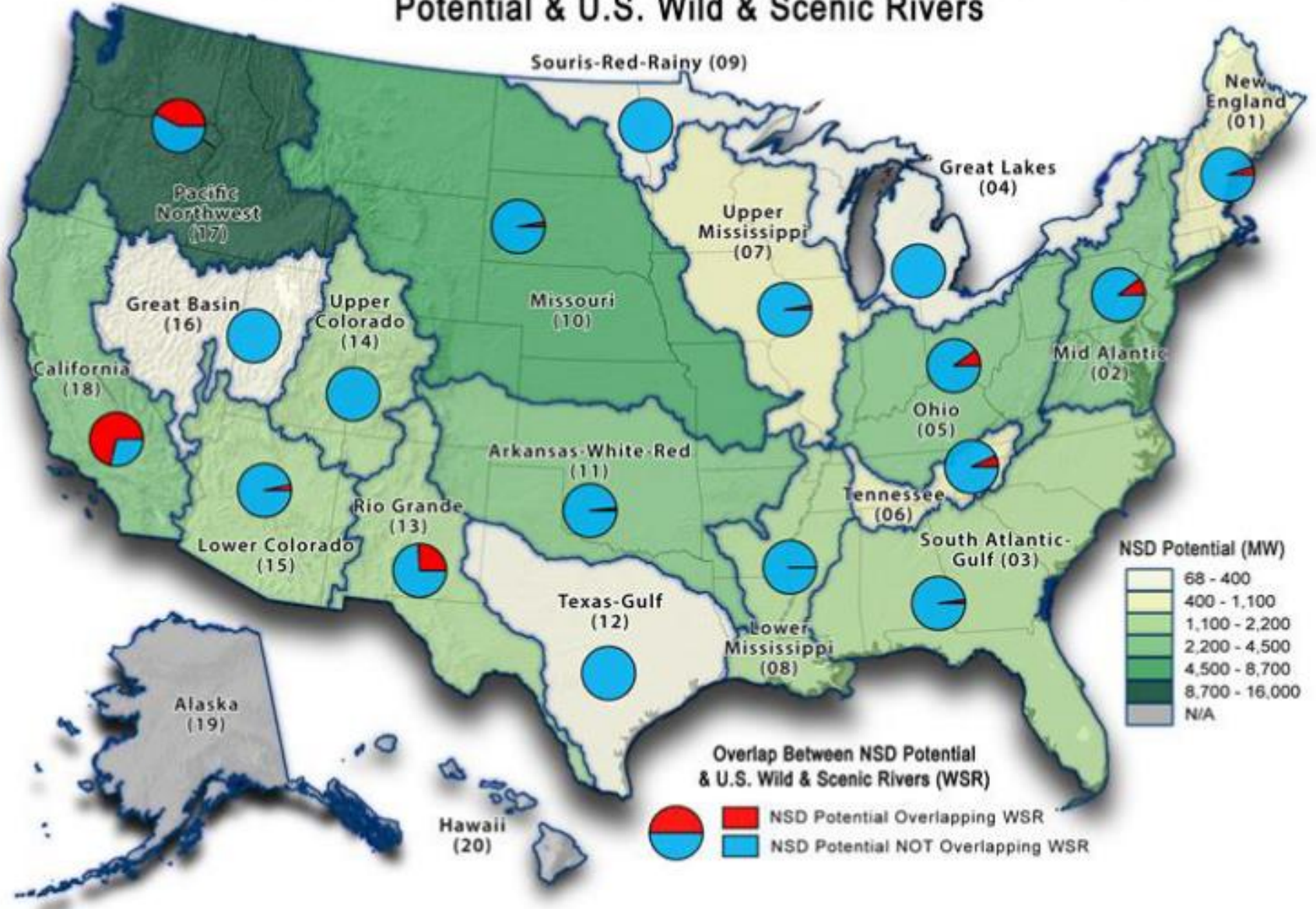
Overlap By Region Between New Stream-reach Development (NSD) Potential & Water Quality Concerns in the U.S.



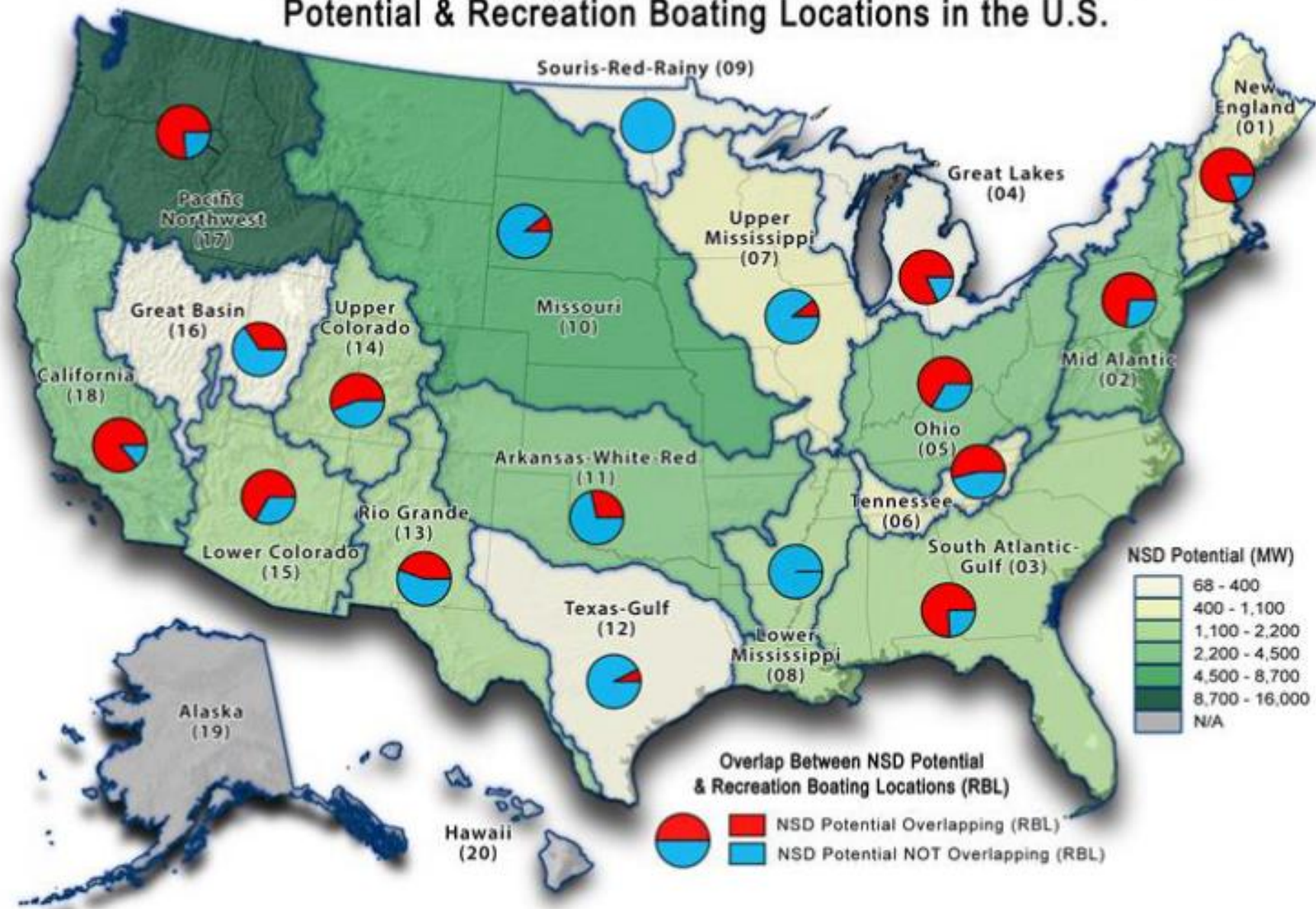
Overlap By Region Between New Stream-reach Development (NSD) Potential & U.S. National Park Lands



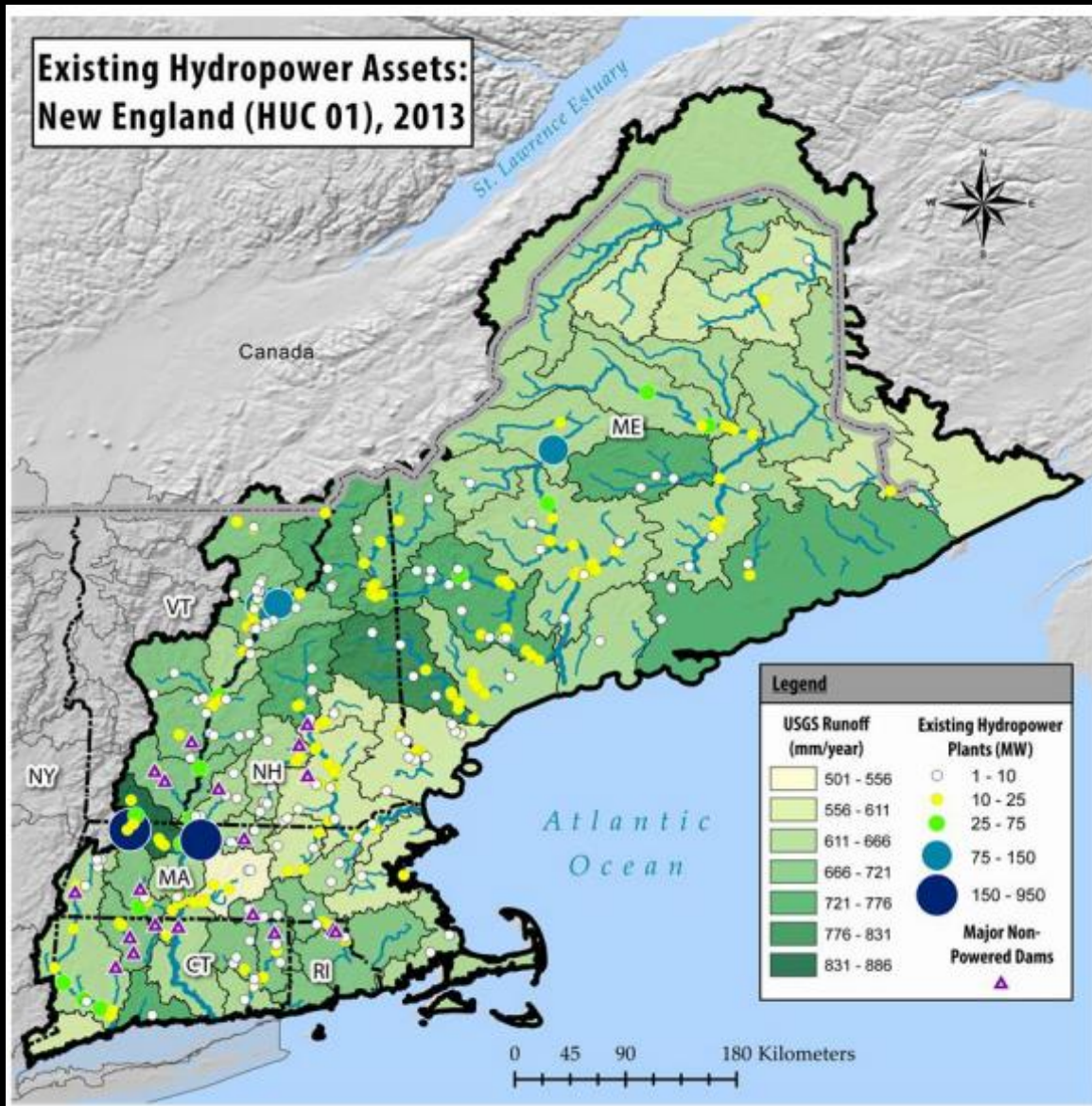
Overlap By Region Between New Stream-reach Development (NSD) Potential & U.S. Wild & Scenic Rivers



Overlap By Region Between New Stream-reach Development (NSD) Potential & Recreation Boating Locations in the U.S.



**Existing Hydropower Assets:
New England (HUC 01), 2013**



**New Hydropower Potential:
New England (HUC 01), 2013**

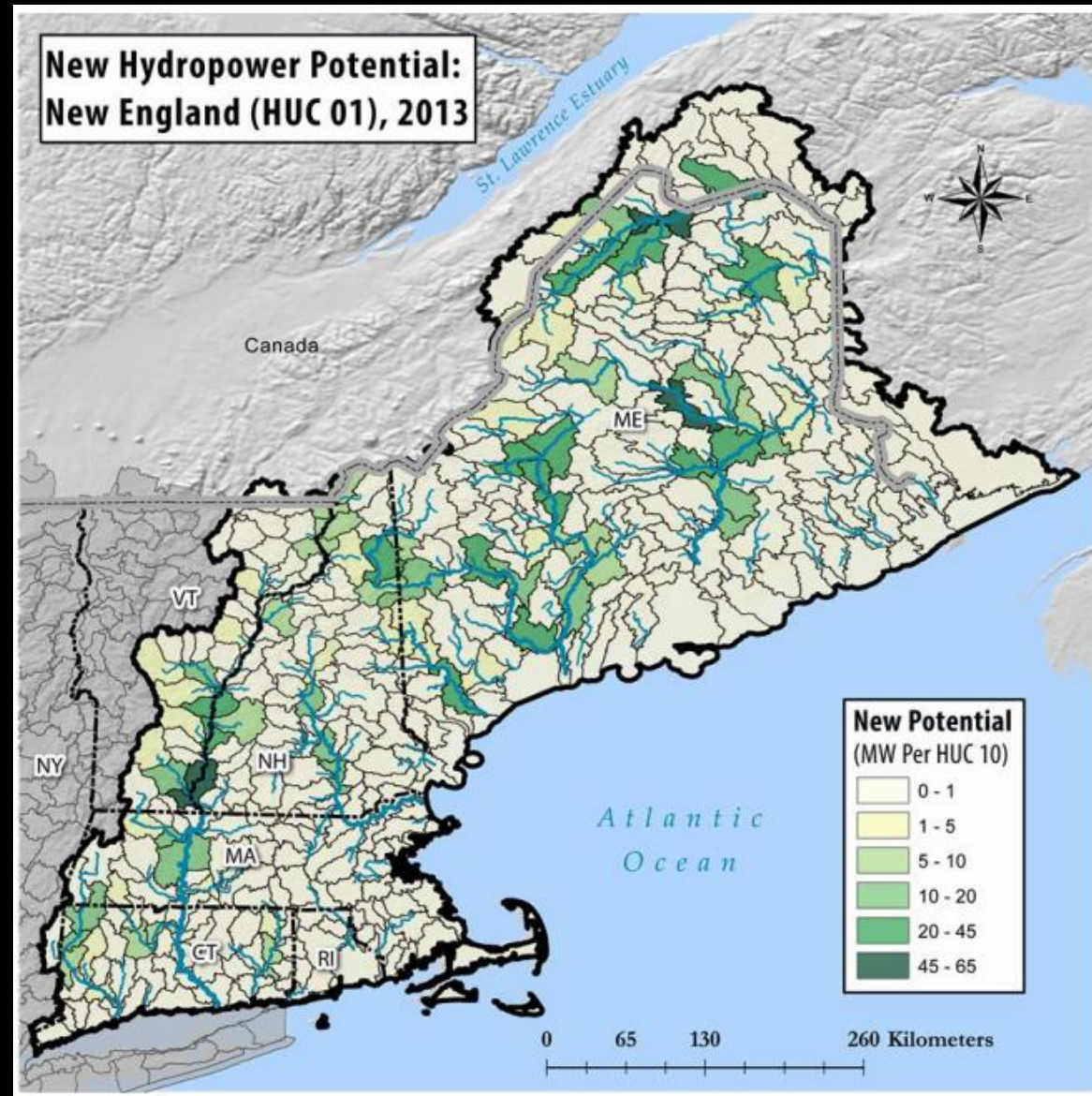
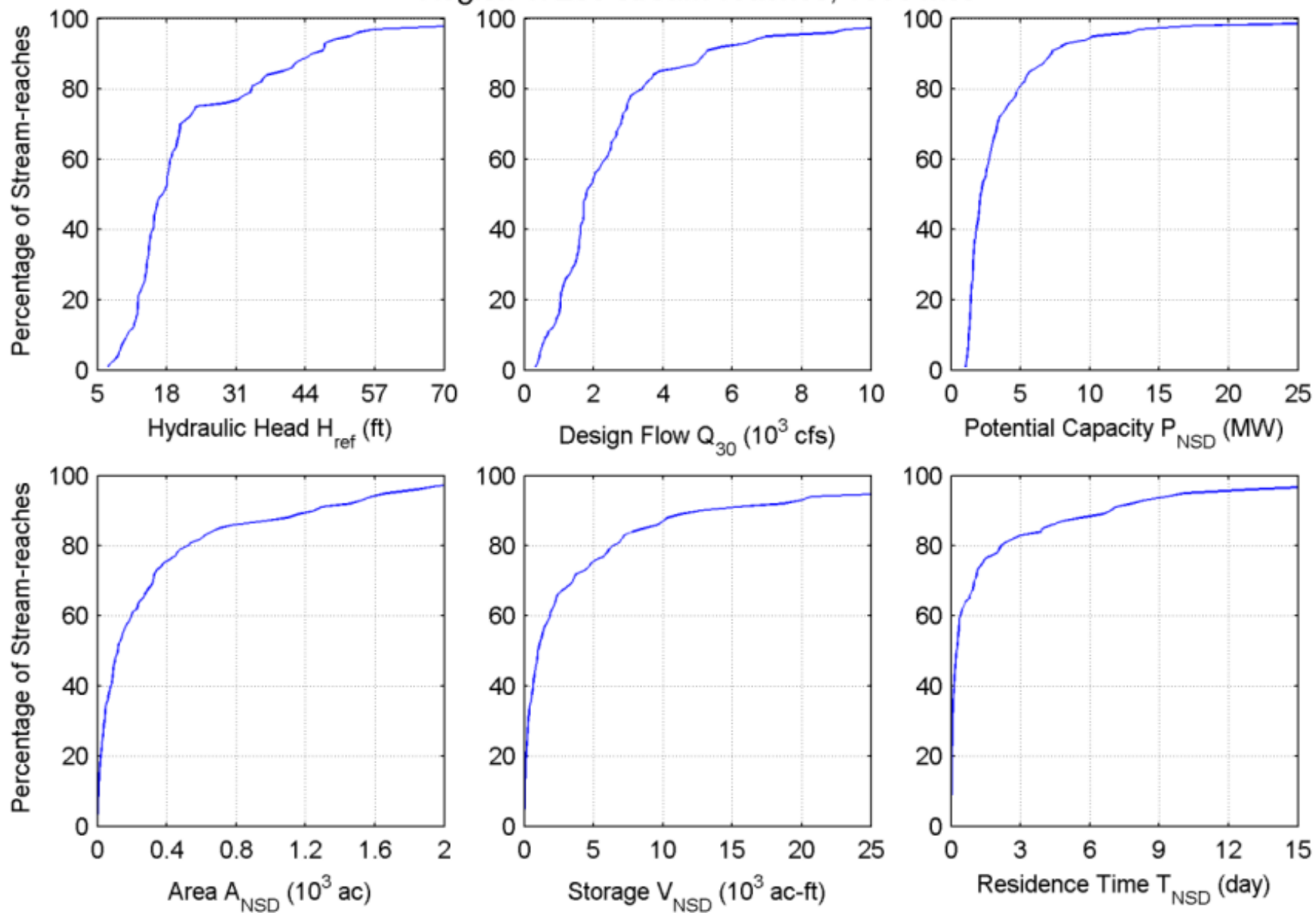


Table 4.1. Summary of NSD Findings in Region 1—New England

	Capacity (MW)	Generation (MWh/year)	Mean Capacity factor
Potential in undeveloped stream-reaches (>1 MW)	1,050	6,161,000	67%
Potential in undeveloped stream-reaches (<1 MW)	1,093	6,272,000	66%
Existing hydropower—conventional hydro	1,821	7,436,000	47%
Existing hydropower—pumped storage	1,571		

Summary of NSD Hydropower Potential (stream-reaches with capacity > 1 MW)
Region 1: 283 stream-reaches, 1050 MW



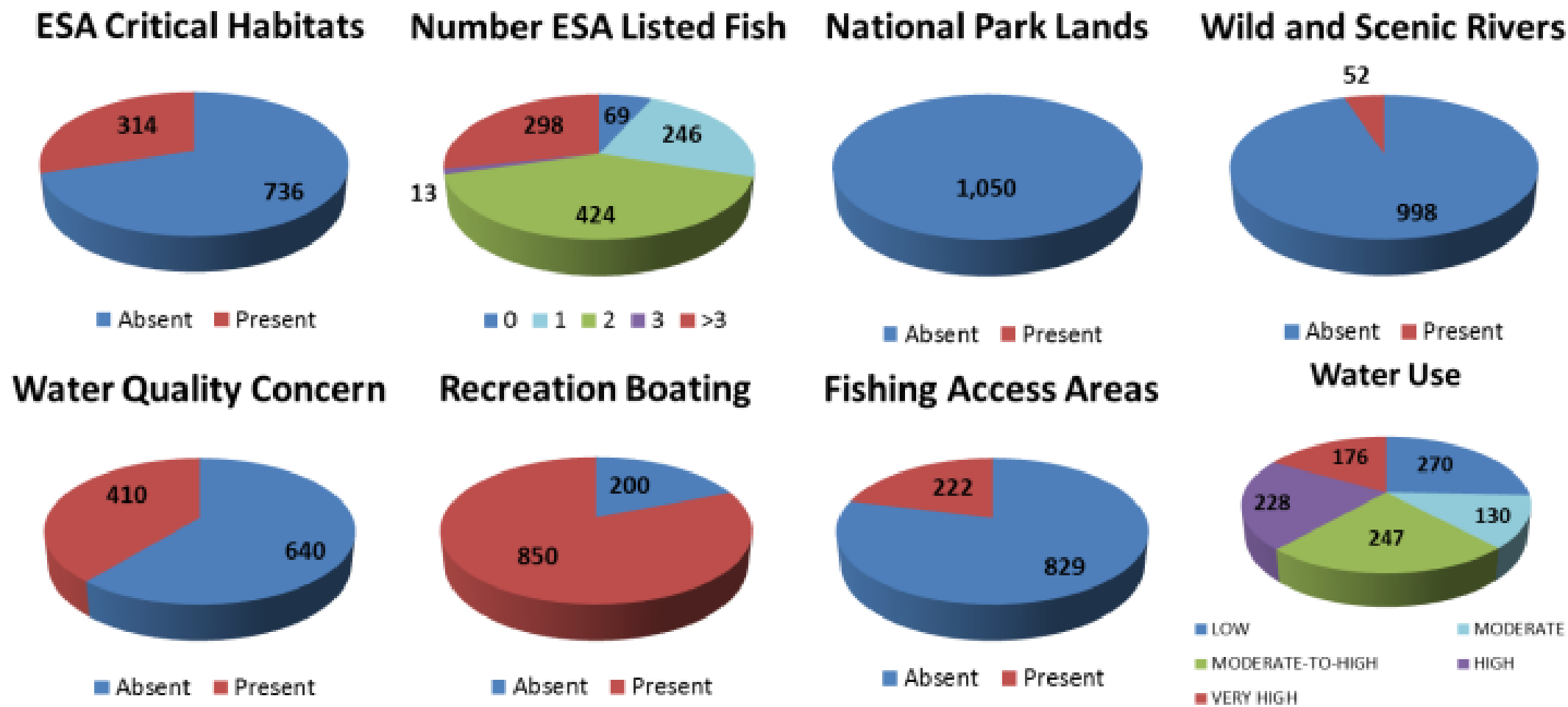


Figure 4.7. The potential capacity, in MW, associated with environmental attributes in Region 1—New England (stream-reaches with potential capacity >1 MW).

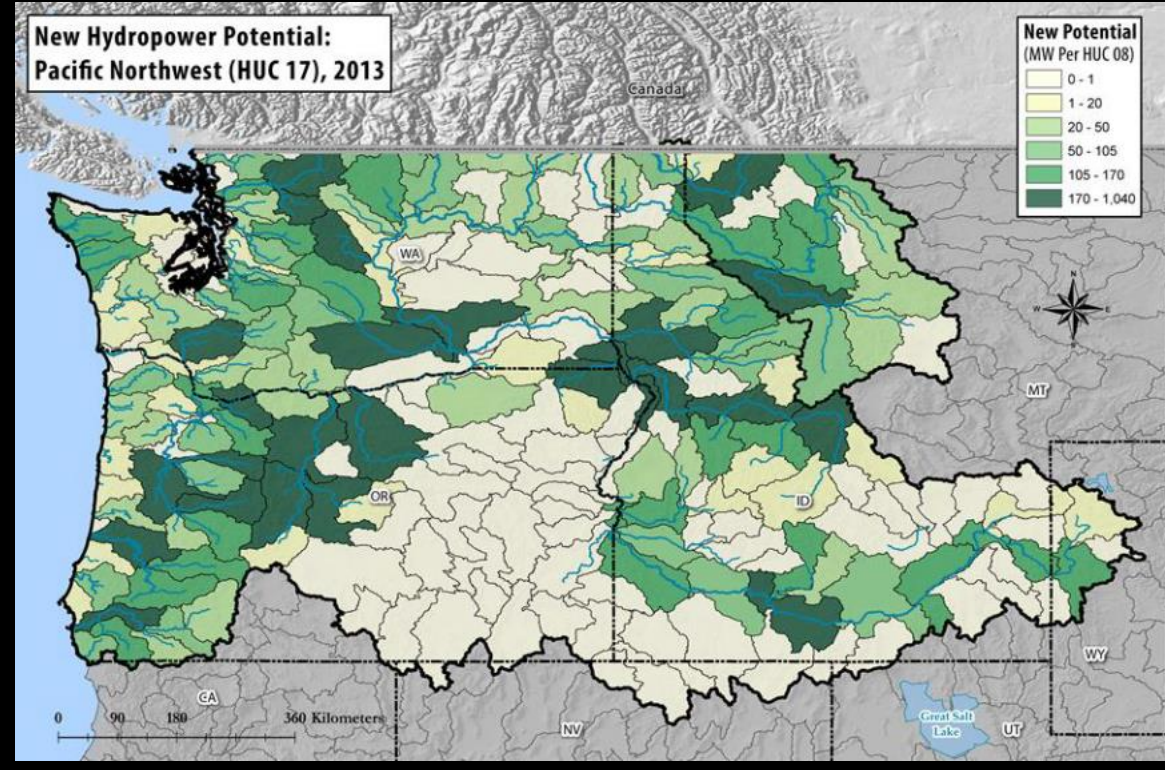
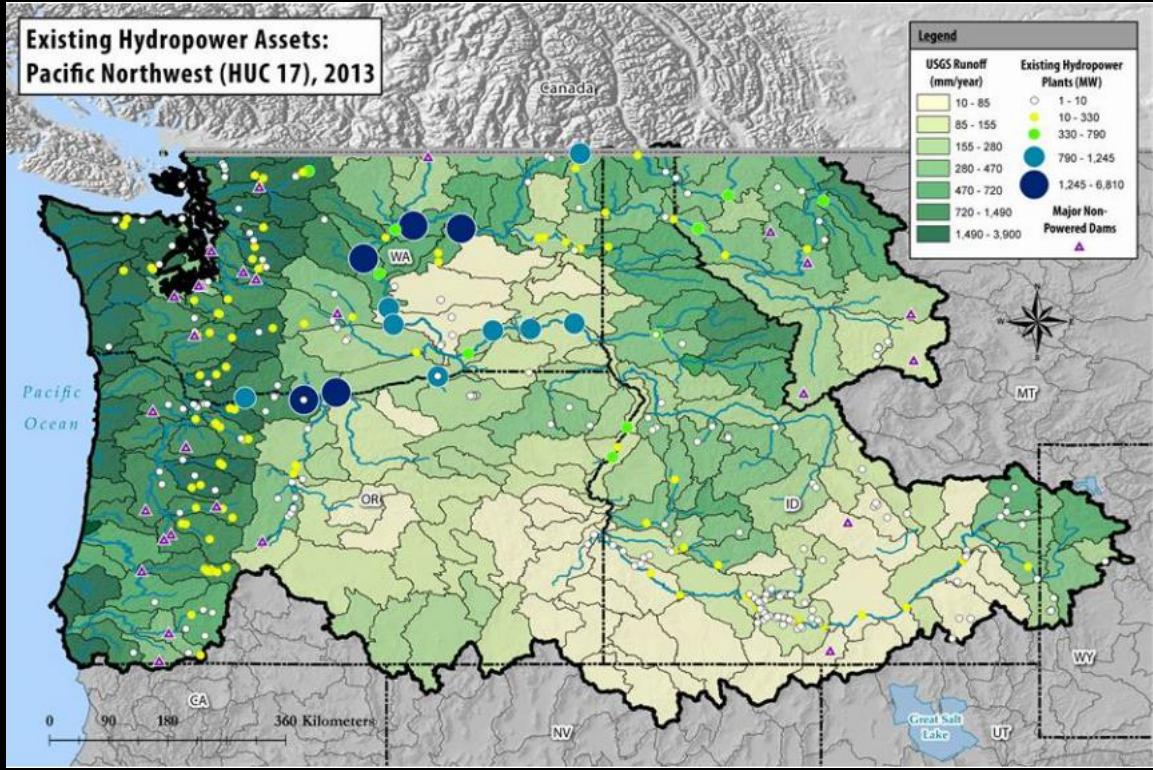
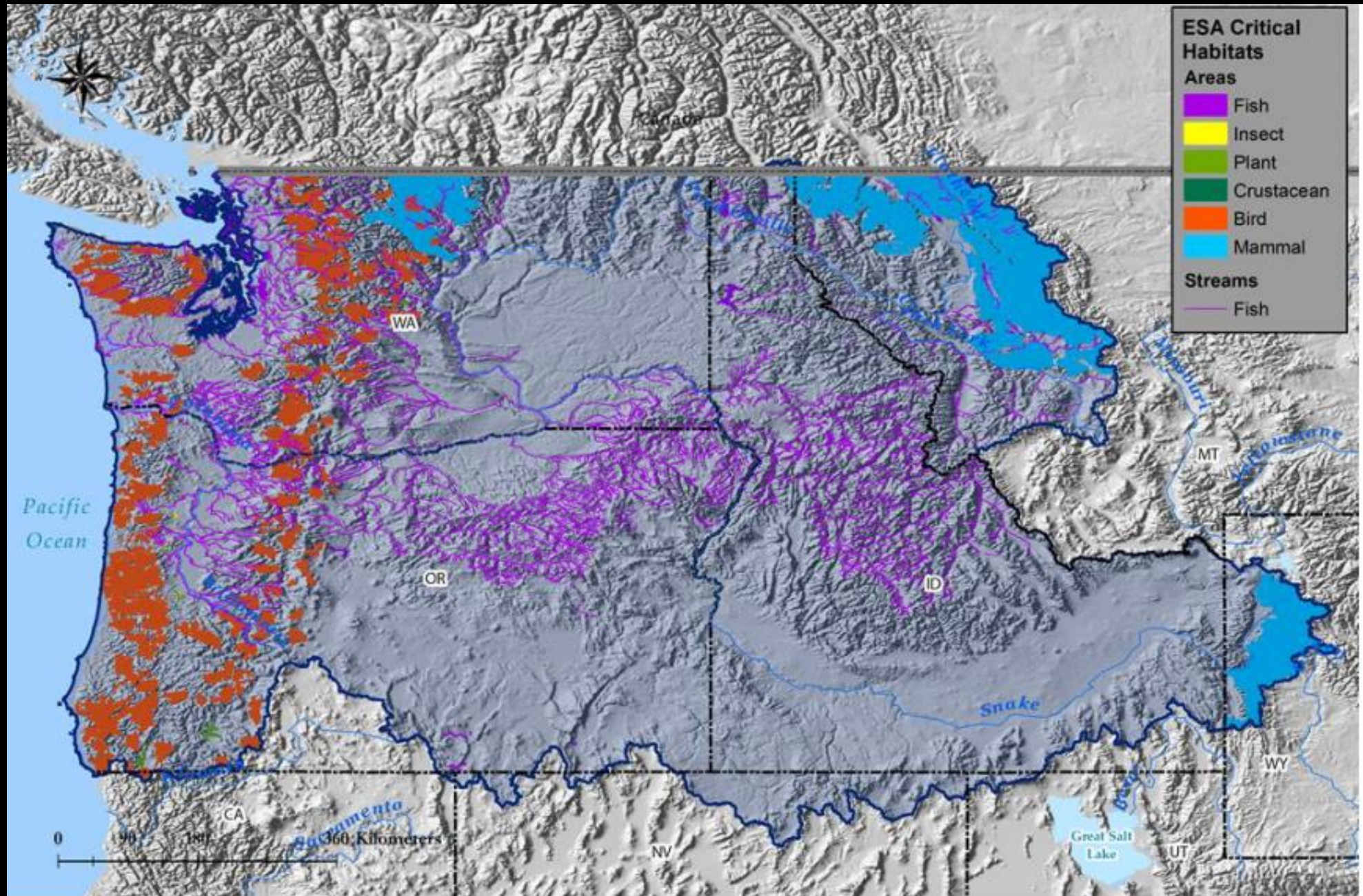


Table 20.1. Summary of NSD Findings in Region 17—Pacific Northwest

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	15,997	96,756,000	69%
Potential in undeveloped stream-reaches (<1 MW)	9,228	52,244,000	65%
Existing hydropower—conventional hydro	33,324	126,084,000	43%
Existing hydropower—pumped storage	314		



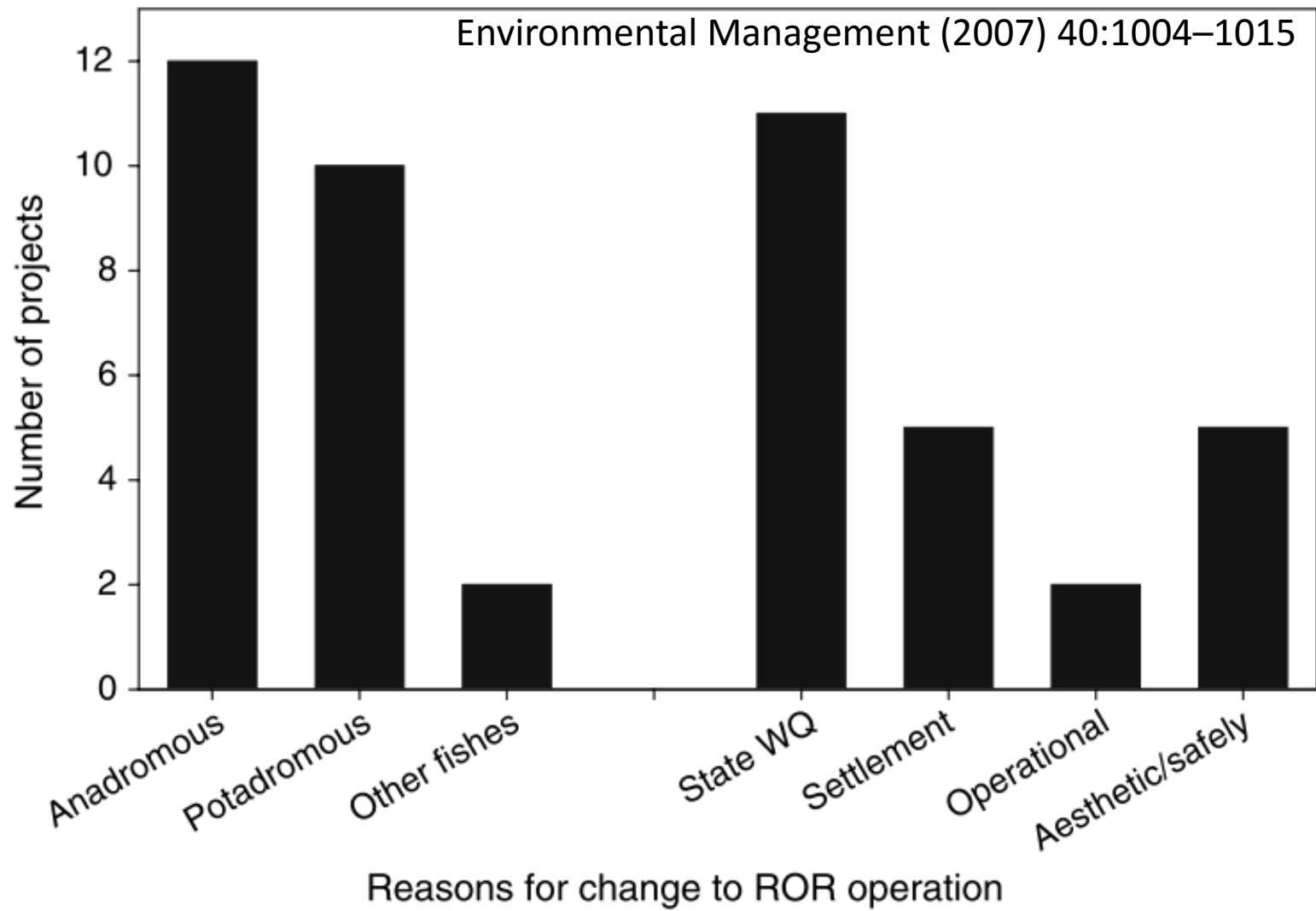
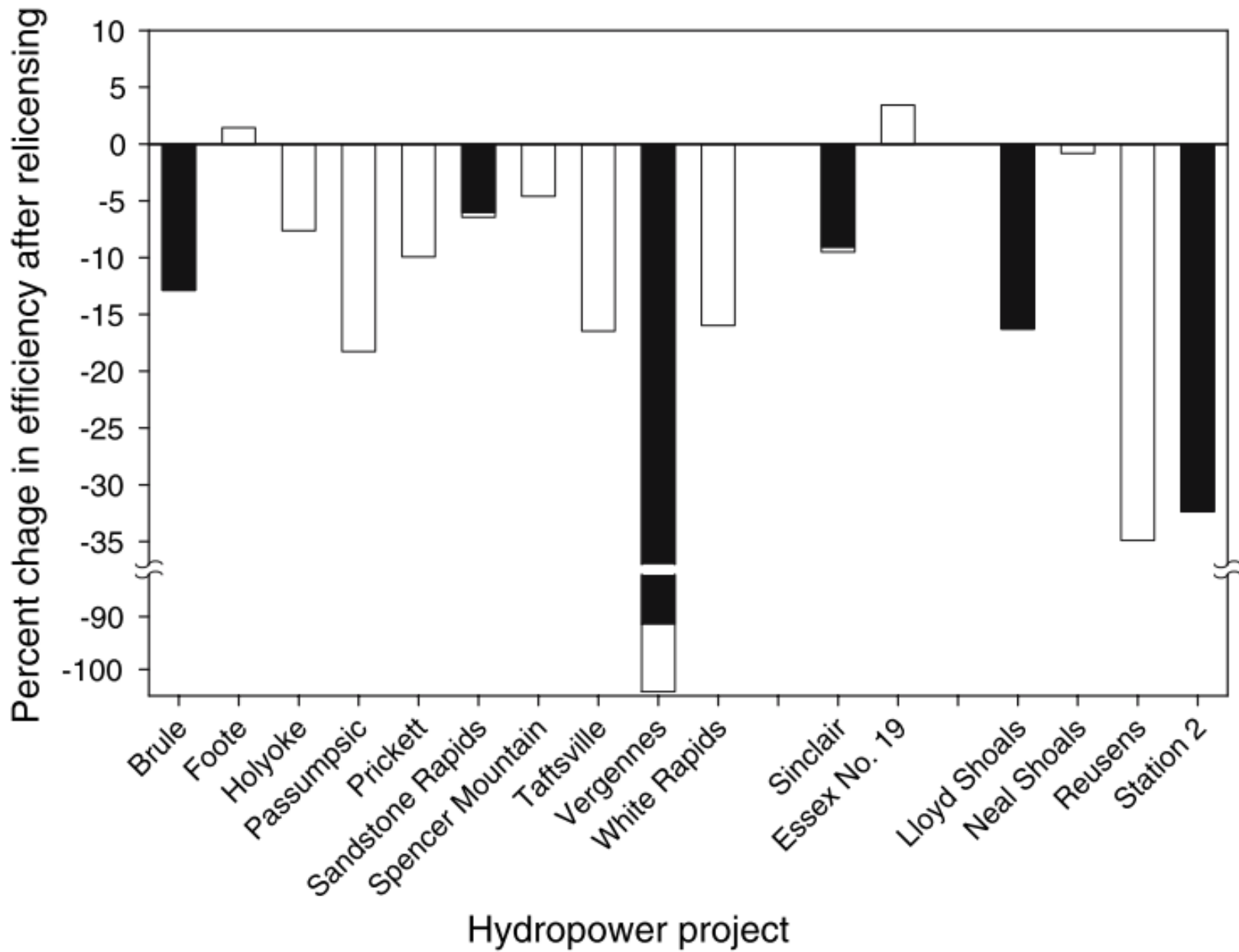


Fig. 2 Reasons listed for required change in operation from peaking to ROR or seasonal ROR. Categories are not mutually exclusive



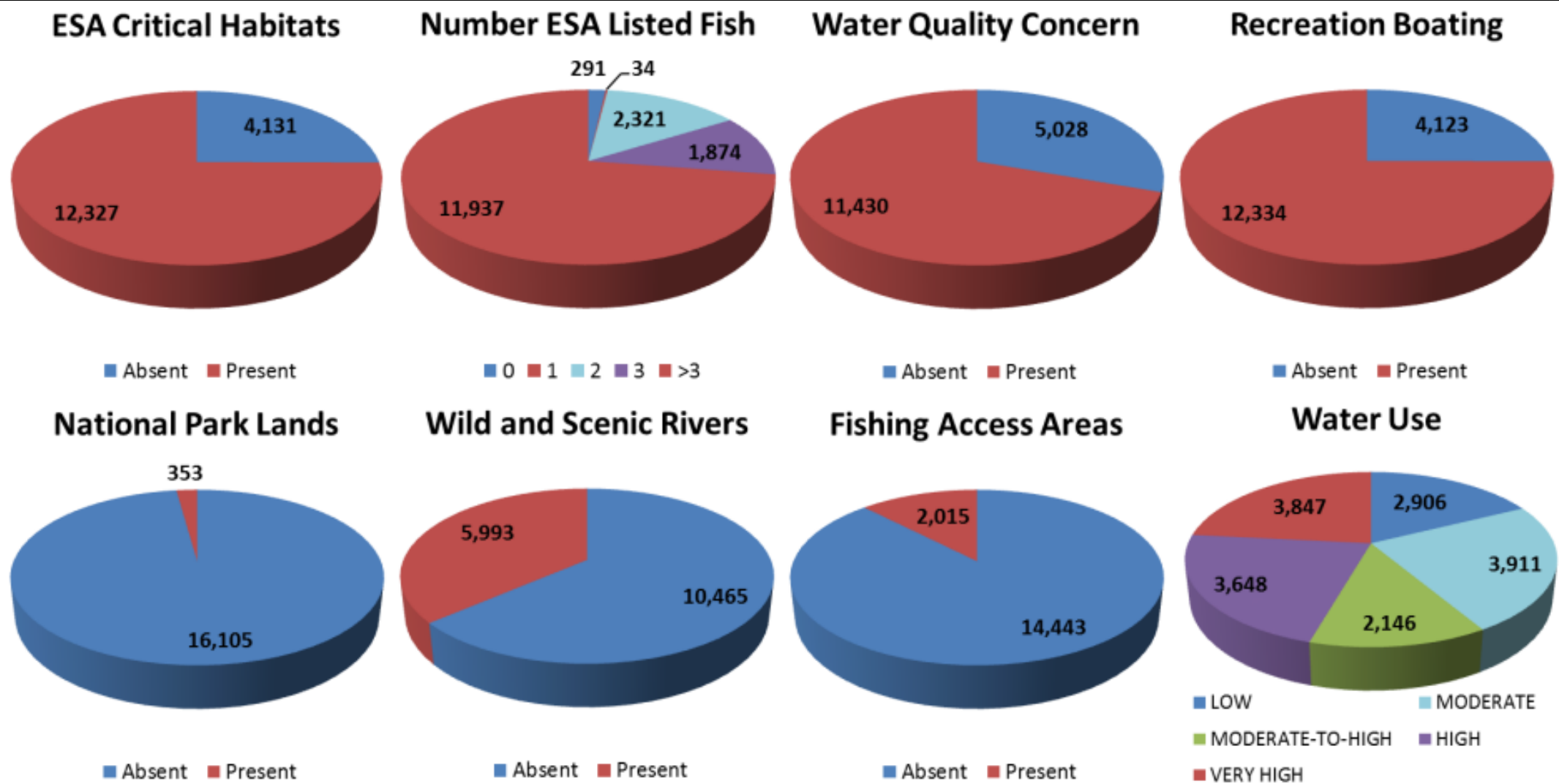


Figure 20.8. The potential capacity, in MW, associated with environmental attributes in Region 17—Pacific Northwest (stream-reaches with potential capacity >1 MW).

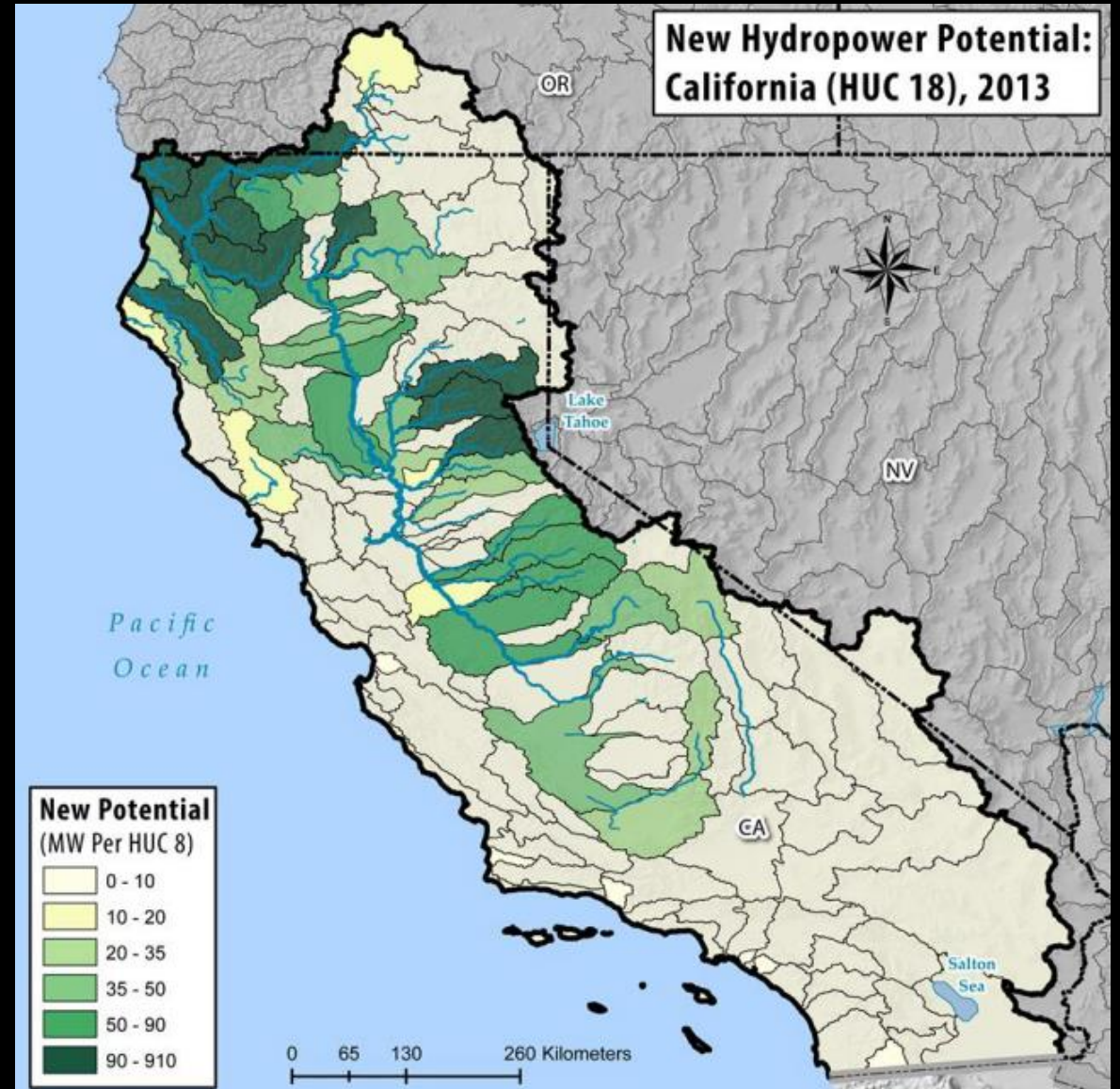
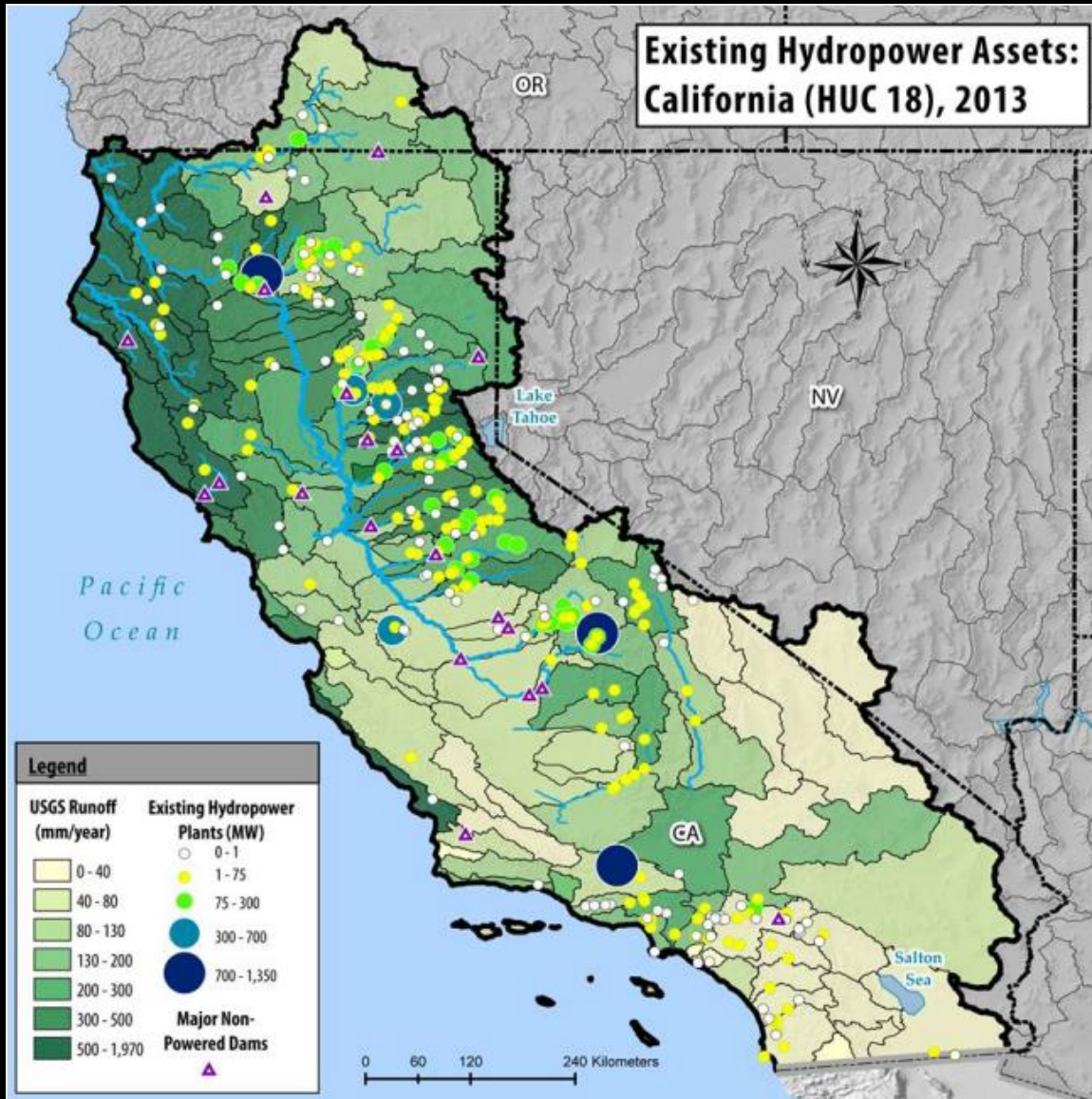
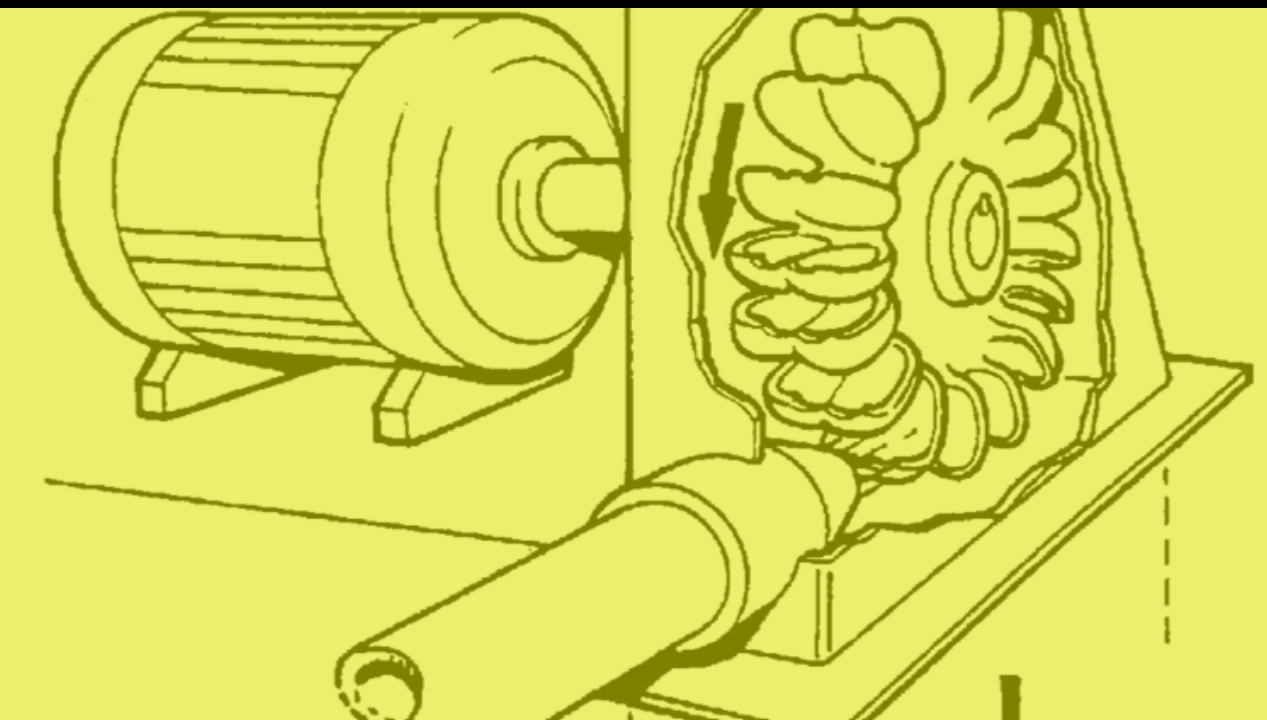
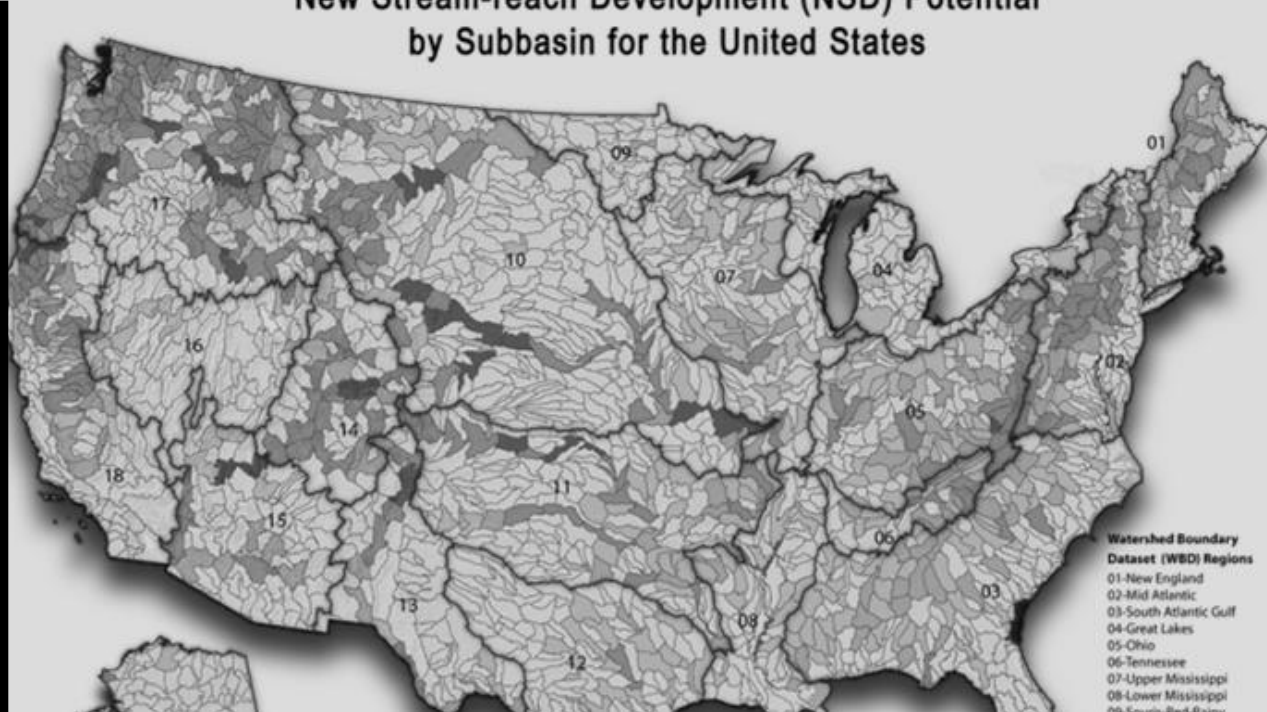
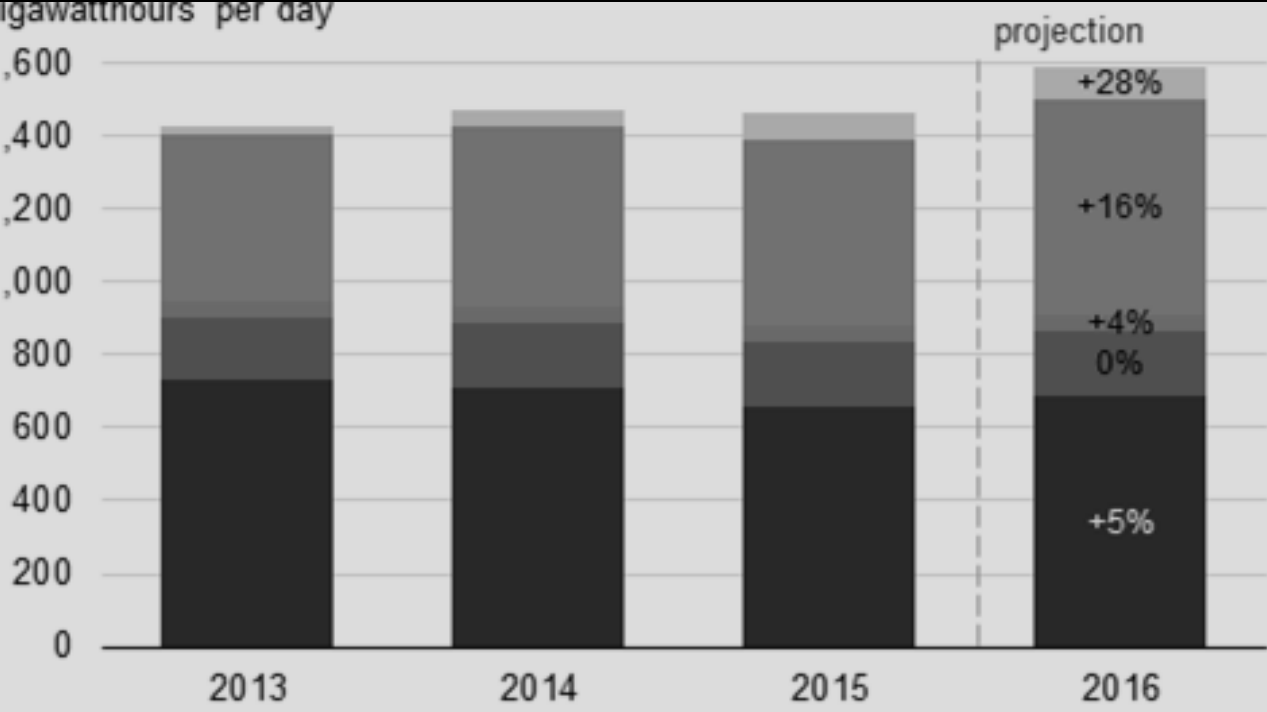


Table 21.1. Summary of NSD Findings in Region 18—California

	Capacity (MW)	Generation (MWh)	Mean capacity factor
Potential in undeveloped stream-reaches (>1 MW)	4,029	22,108,000	63%
Potential in undeveloped stream-reaches (<1 MW)	3,025	15,879,000	60%
Existing hydropower—conventional hydro	10,292	34,034,000	38%
Existing hydropower—pumped storage	3,393		



$$\frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

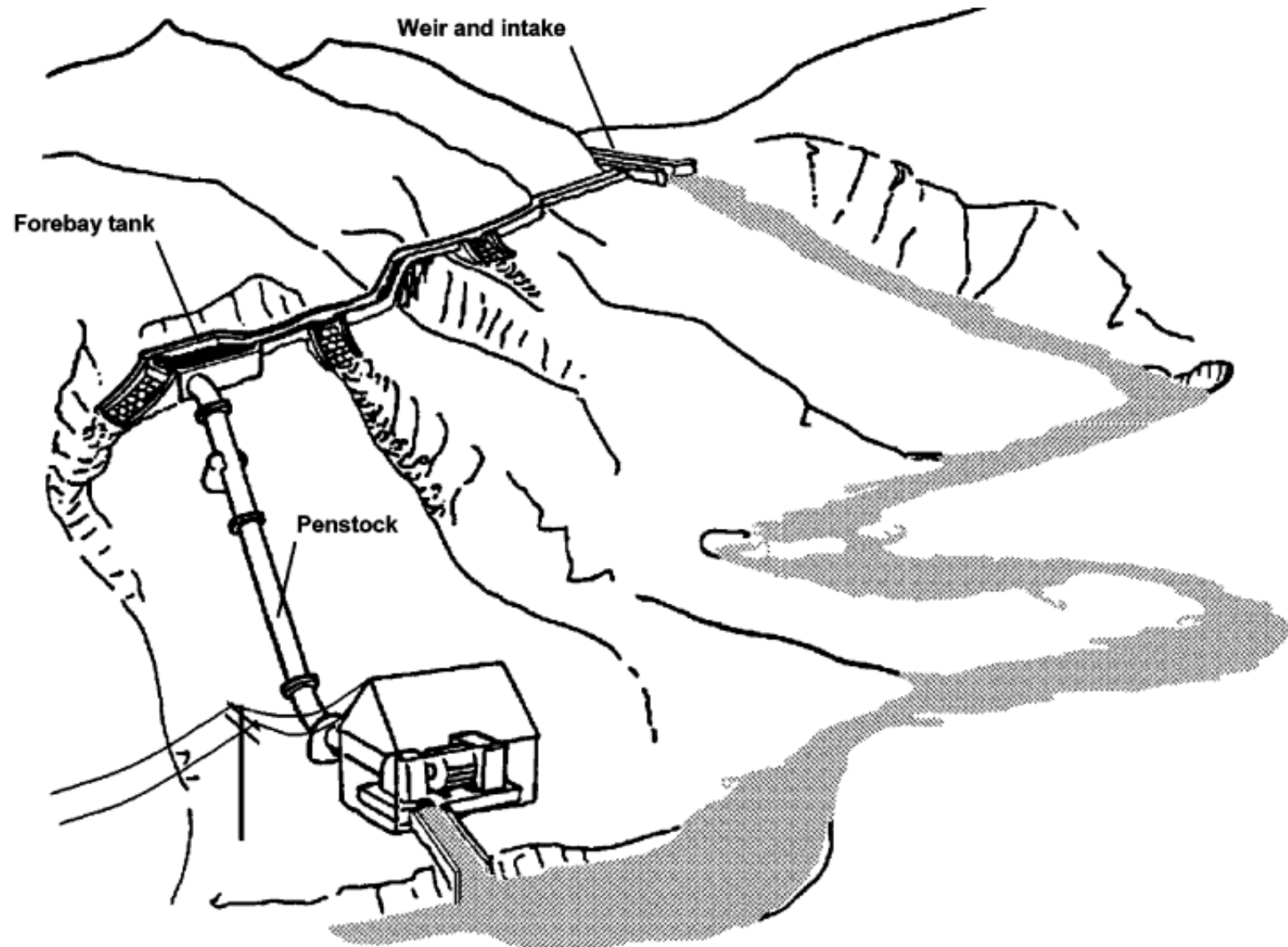
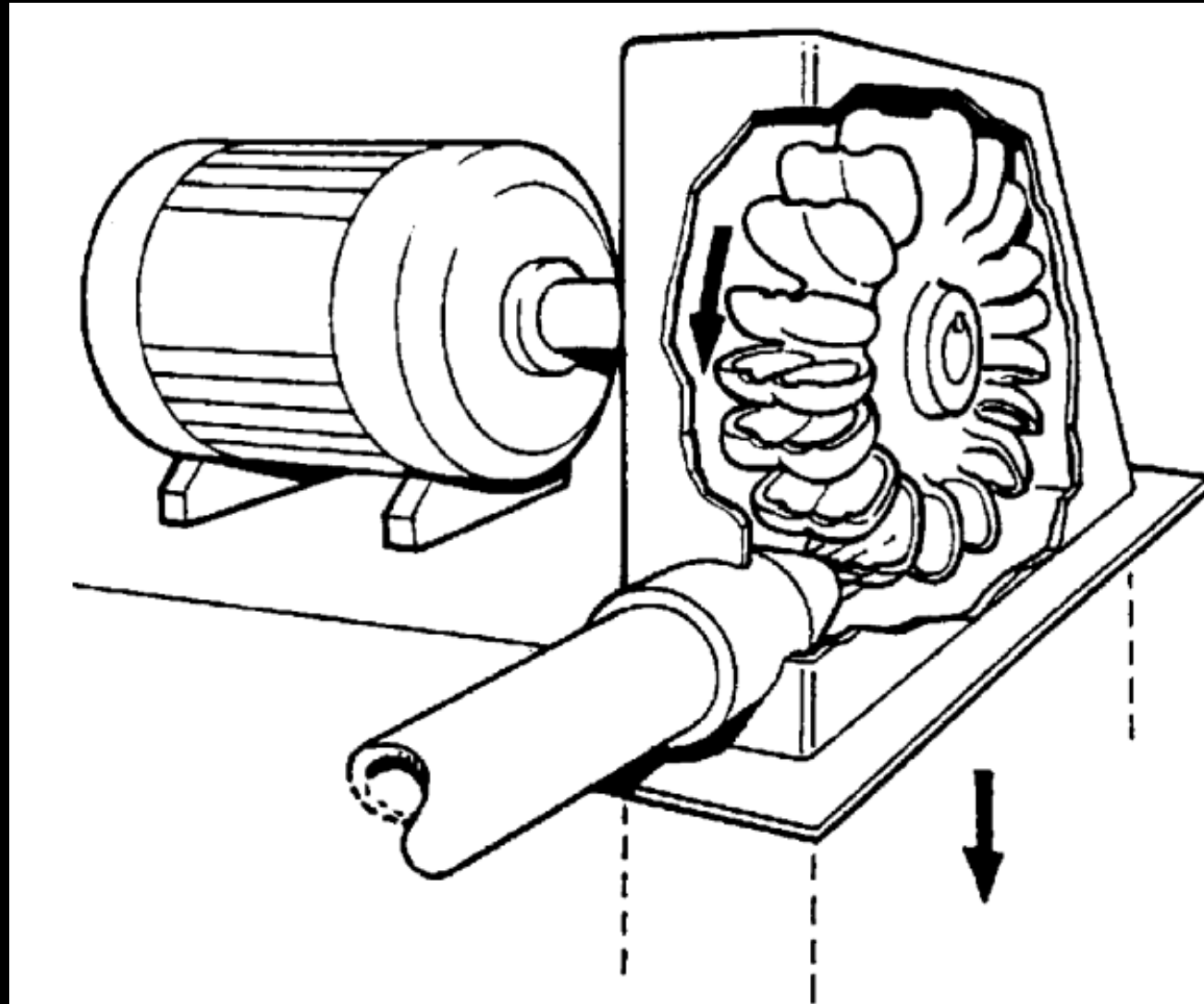
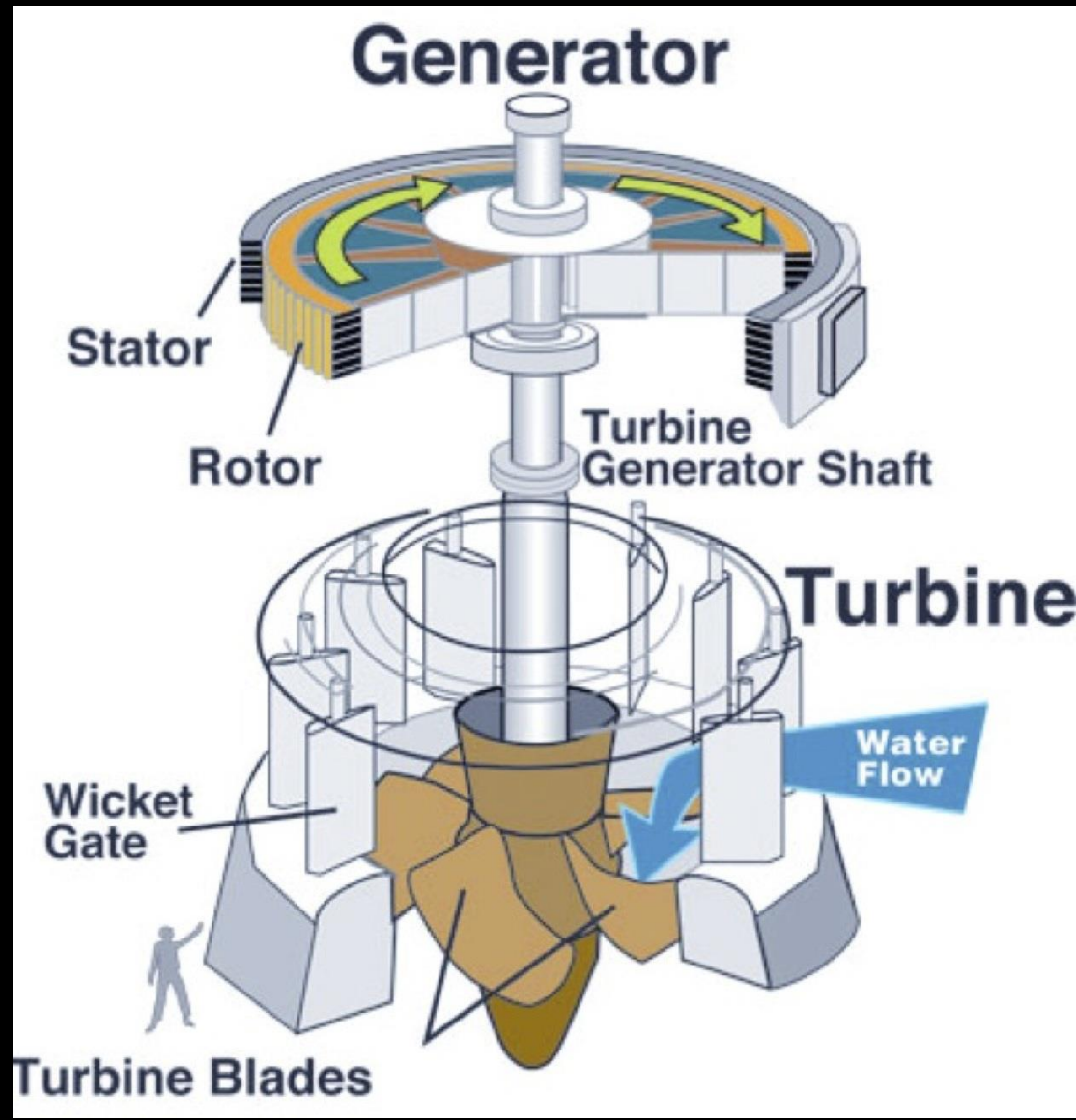


Fig. 2. Small hydro site layout.

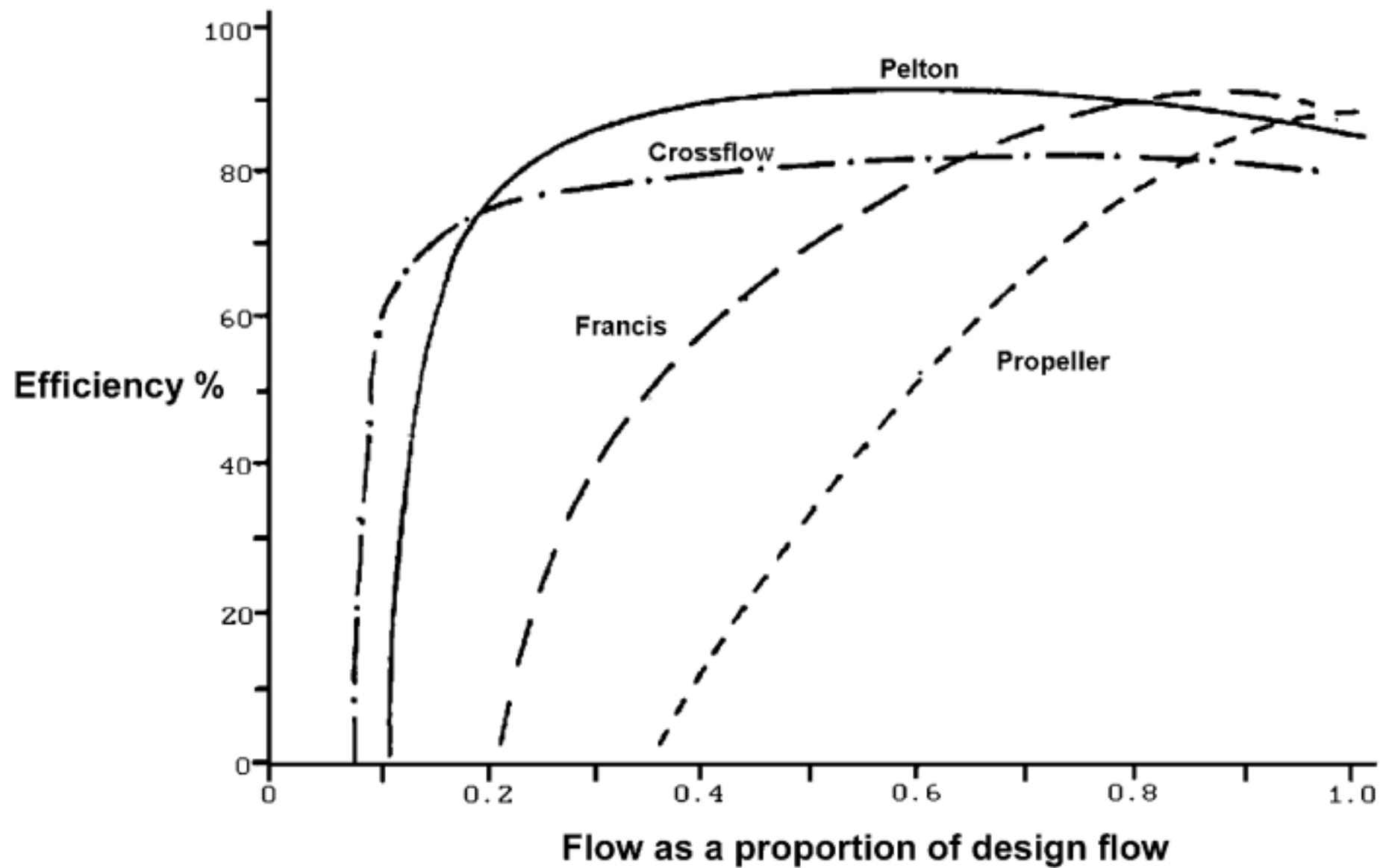
Turbine type	Head classification		
	High (>50 m)	Medium (10–50 m)	Low (<10 m)
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis (spiral case)	Francis (open-flume) Propeller Kaplan



Pelton (impulse)



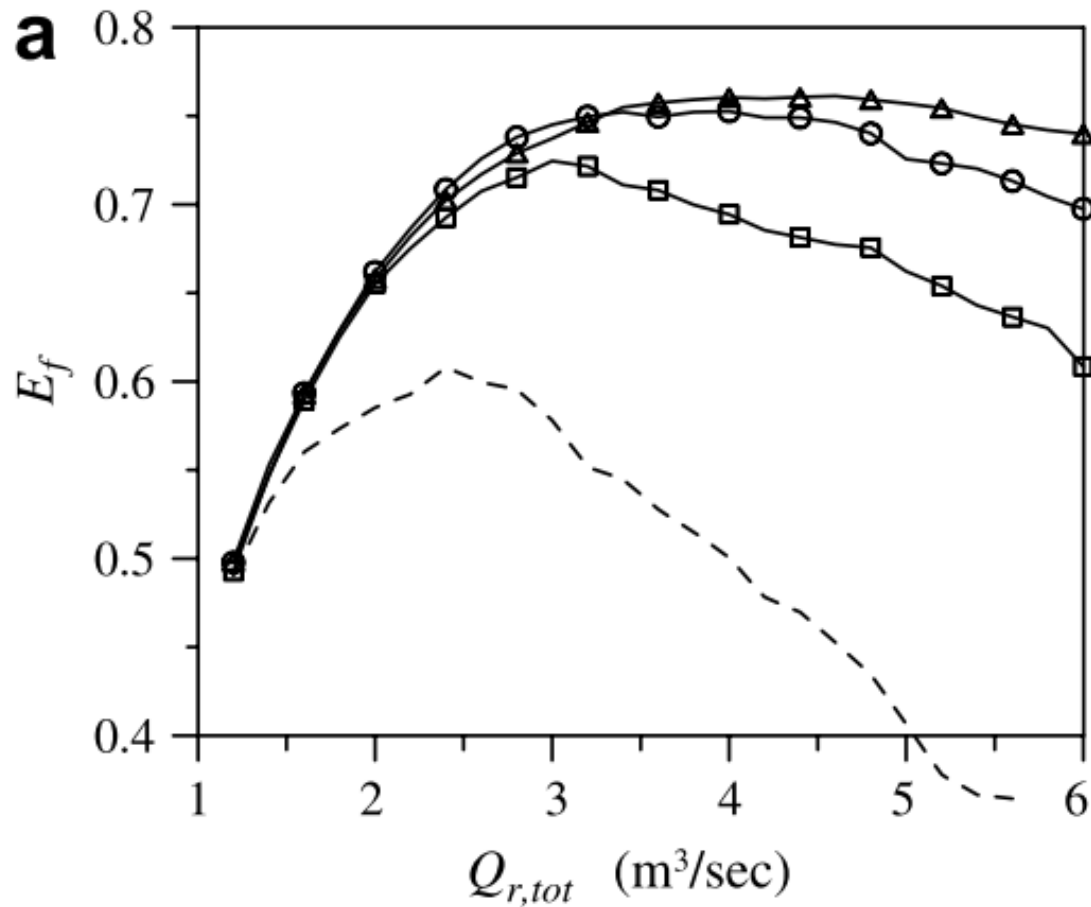
Francis (reaction)



Future Improvements

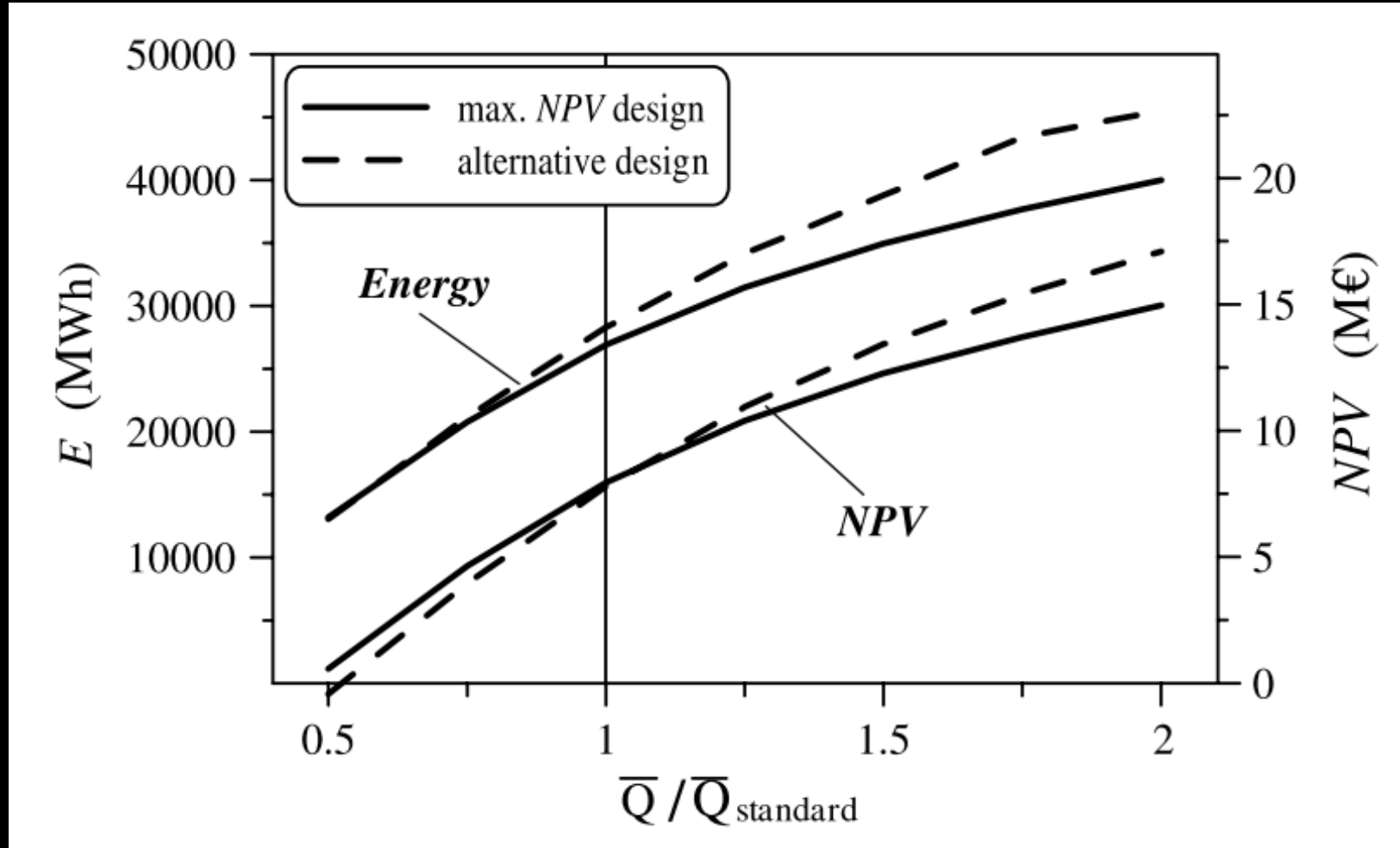
- *Variable speed operation of low head turbines:* recent developments in power electronics allow a turbine and generator to be run at varying speeds (instead of synchronous speed needed to produce the mains standard of 50 Hz AC). This permits simpler propeller turbines to be used instead of Kaplans.
- *Inflatable weirs:* water-filled rubber weir crests are being used to raise the available head on low-head sites; they can deflate to allow flood waters to pass through.
- *Improved techniques to avoid interference or damage to fish:* perhaps the most common objection to new hydro systems is that they may harm fish. Novel forms of fish ladder and physical or ultra-sonic screening promise more cost-effective solutions.

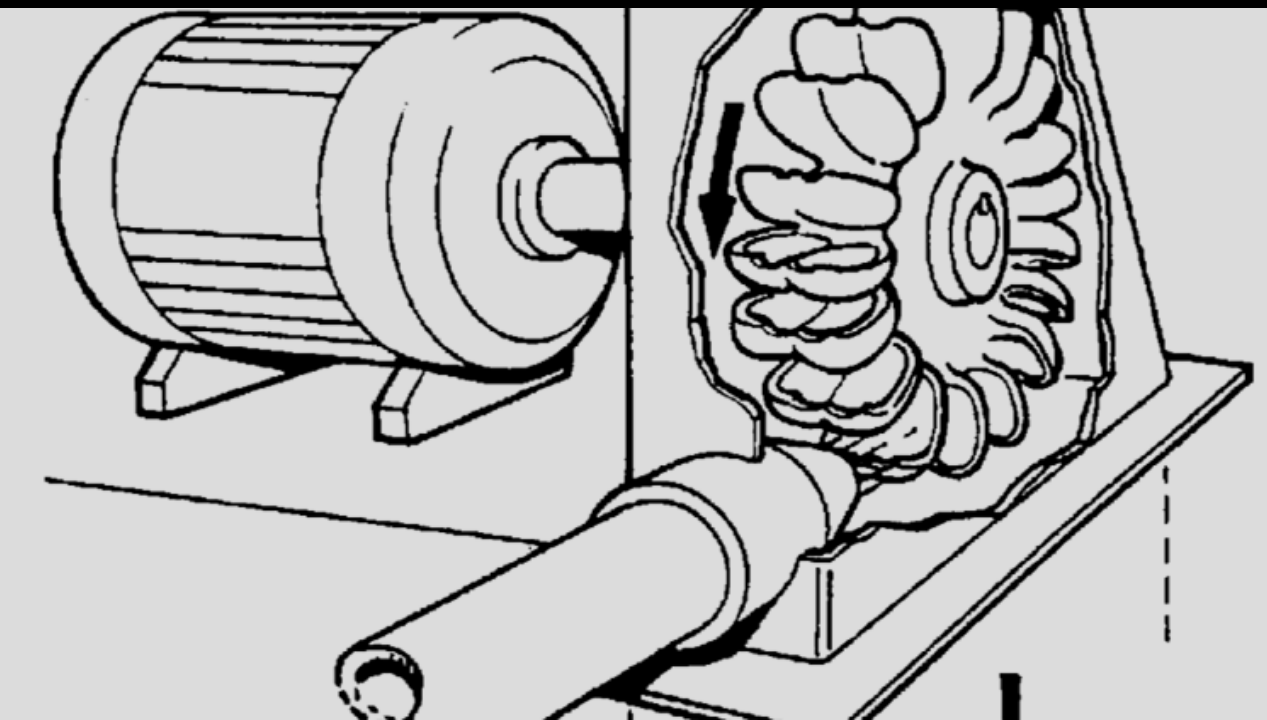
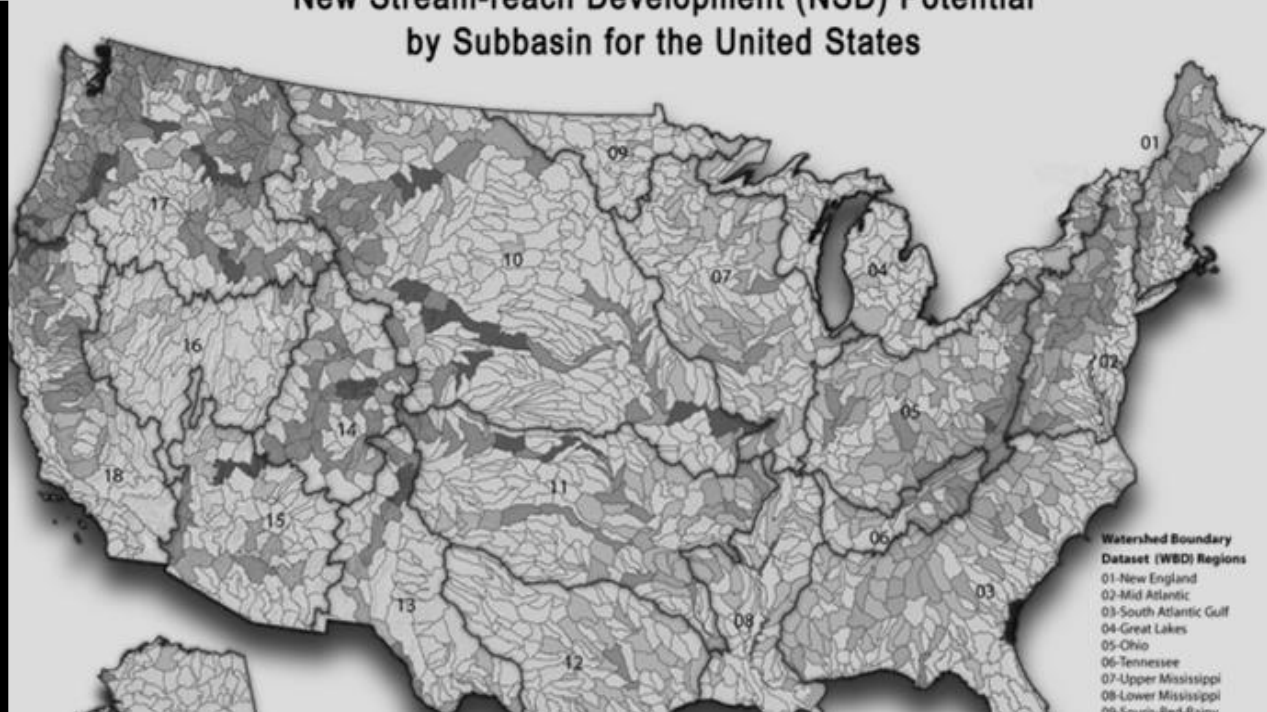
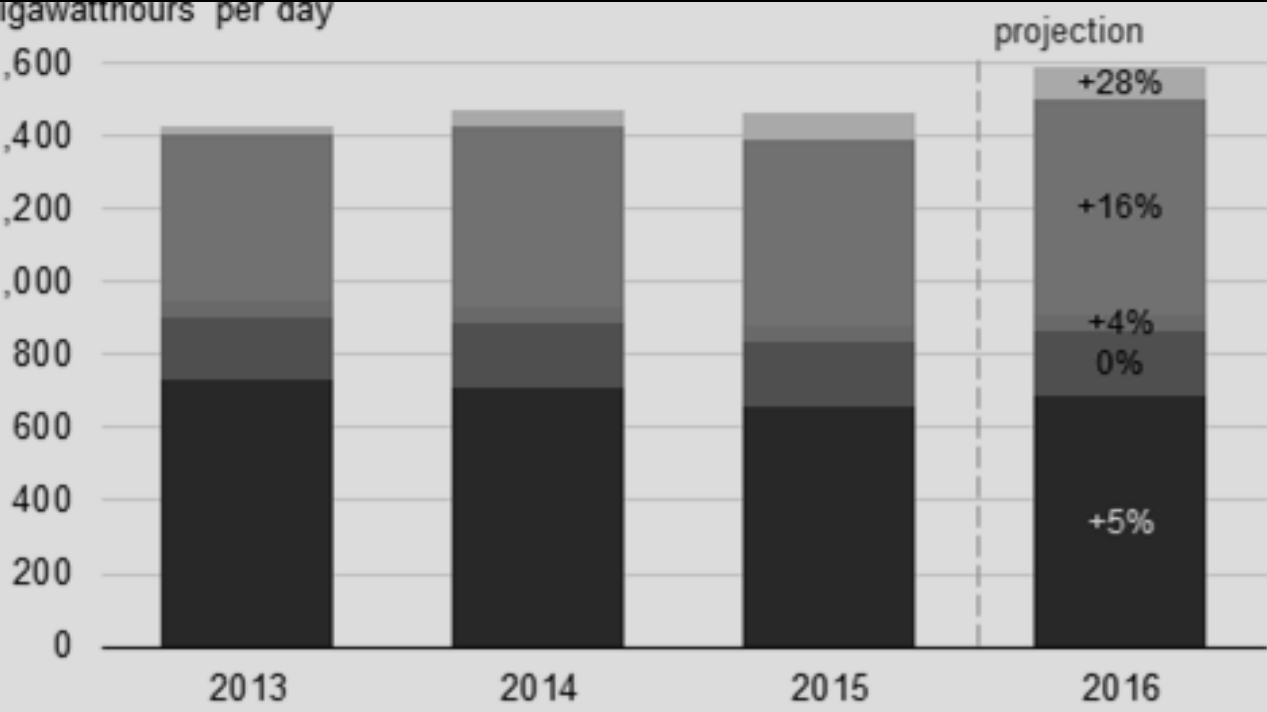
Two Turbines



- (1) $Q_S < Q_{2,min}$: Both turbines shut down. No energy production.
- (2) $Q_{1,min} < Q_S < Q_{1,max}$: One turbine (T2) in operation.
- (3) $Q_{2,min} < Q_S < Q_{2,min}$: One turbine (T2 or T1) in operation, whichever achieves the best efficiency.
- (4) $Q_{2,max} < Q_S < Q_{1,max}$: One turbine (T1) in operation.
- (5) $Q_{1,max} < Q_S < Q_{1,max} + Q_{2,min}$: Both turbines in operation, optimum Q_T distribution.
- (6) $Q_{1,max} + Q_{2,min} < Q_S < Q_{1,max} + Q_{2,max}$: Both turbines in operation, optimum Q_T distribution.
- (7) $Q_{1,max} + Q_{2,max} < Q_S$: Both turbines in operation at maximum flow rate $Q_{T,max} < Q_S$.

Two Turbines





$$\frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Levelized Cost of Electricity

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

LCOE = the average lifetime levelised cost of electricity generation;

I_t = investment expenditures in the year t ;

M_t = operations and maintenance expenditures in the year t ;

F_t = fuel expenditures in the year t ;

E_t = electricity generation in the year t ;

r = discount rate; and

n = economic life of the system.

