NYSERDA REV Campus Challenge Micro Hydro | Macro Impact Project

Navigating Micro Hydropower Options

A decision-making framework for the technical feasibility of non-powered dams and dam-free micro hydropower

Prepared for

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Introduction

New York State has more than 6,800 historic, non-powered dams. Depending on a variety of social, environmental and technical factors, a share of these dams can be upgraded to generate electricity as a **(non-powered dam) micro hydropower project**. But not only dams can be upgraded to generate electricity, also waterfalls and other natural elevation changes to so-called **dam-free micro hydropower projects**. And there are many good reasons to do either, e.g. to fight climate change, to become more climate resilient, for financial reasons[1], to become autonomous from the electric grid, or for a combination of all or some of these and other reasons.

This flowchart (see: *Appendix: Decision-Making Framework Flowchart*) was developed to help owners of a stream-side property (with non-powered dams or dam-free) to assess their micro hydropower potential and design their general system layout. The visual flowchart will assist navigation for stakeholders who have taken the option to install micro hydropower focusing on technical feasibility and potential "fatal flaws". A detailed description of various self-assessment steps and options, as well as recommendations and necessary considerations are provided in this handbook.

This decision-making framework, in the form of a flowchart, is based on lessons learned throughout the demonstration micro hydropower project at Bard College[2]. The Decision-making Framework aims to assist interested parties in navigating their micro hydropower options and focuses on a project's technological feasibility, considering the starting point (i.e. existing dam, no dam, other infrastructure), key decision points and potential fatal flaws (i.e. head, flow, proximity to utility infrastructure, system size, navigable waterway), and will suggest a micro hydropower design. Notes on environmental, financial and social factors are included as far as relevant for the technical design. This tool does not evaluate whether a dam-site is a good candidate for micro hydropower or not.

The Framework, following this short introduction, consists of two simple flowcharts – one for non-powered dam micro hydropower projects and one for dam-free micro hydropower projects - easily digestible by a variety of stakeholders regardless of hydropower expertise. Please consider the sections below which contain instructions and additional information. This report and the decision-making framework will be publicly available via the microhydroNY.org-website.

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[1] Owning a dam requires a certain amount of annual budget to fulfill assessment and reporting requirements and conduct dam maintenance. Installing a successful micro hydropower project, would generate a revenue stream that covers those maintenance costs and provides a payback after a certain period of time; external investors can help the project with reducing the owner's upfront investment.

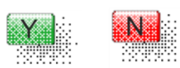
[2] See https://microhydrony.org/ for more information.

Working through the flowchart, you will come across five (5) types of operators:

The **Action Operators** tell you what to do next. They guide through the flowchart and help you design your micro hydropower system. Keep notes when an **Action Operator** recommends specific type of actions and considerations for your system design.

The **Or Operator** (Or) gives you an alternate path after an Action Operator. Or operators are connected via dotted lines.

The **Question Operators** offers you a choice: depending on your answer the flow through the chart will go in a different direction.



Answer Operators (Y:Yes; N: No) are the possible reaction to Question Operators.

The **Assessment Operators** require you to collect specific information with regard to your site, your energy consumption and other local parameters. They also help you gather necessary information for your micro hydropower journey.

The operators are connected with lines and arrows: follow the arrows through the flowchart, using Answer Operators and Or Operators to help you navigate. Arrows can also navigate you to the next page or even back to the beginning of the flowchart if necessary.

All Actions, Questions and Assessments included in the flowchart are discussed in detail in the following sections, in order of appearance:

- Questions: Instructions and Explanations
- Assessment Process
- Actions, Recommendations and Considerations

Questions: Instructions and Explanations

Are you the sole owner of the dam or waterfall?

In most instances, stream-side property lines end in the middle of a stream: one half belongs to one property, the other half to the other property.[3] It also happens that ownership over a dam or a waterfall is split the same way. Further, a very favorable elevation change (see Assessment Processes) might stretch beyond the boundary lines of one property onto the next downstream property. Check your property deed and consult your county's parcel mapper for the exact location of the property line and ownership rights.

Can you develop the site together with your neighbor(s)?

If you don't own all of the necessary properties yourself, you will need an easement[4], or buy the respective parts of the properties, or partner with the current owners of those parts. Many part-owners of dams, are happy to sell their share of the dam or give it up for free to be relieved from the responsibilities of owning a dam (maintenance, fulfilling the requirements of DEC's dam safety department[5], etc.). Selling stream-side property is a different story; people are rather reluctant to give up their access to the stream. To move forward with any kind of permitting for your micro hydropower facility, you will need to have the respective rights! Make sure whatever contractual solution you find with your neighbors, that it outlasts your micro hydropower plans (50 years plus).

Does your stream run dry in the summer?

If your stream runs dry in the summer months, chances are high that a financially successful micro hydropower project is not possible. The necessary changes to the infrastructure, permitting, and maintenance of the facility will only pay off if the facility basically runs 24 hour a day, 7 days a week – throughout the entire year. There can always be days or weeks of extreme drought, where the facility won't be able to operate, but this should be the exception and not a planned part of your operation.

Is the elevation change at your site more than 5 feet?

To assess the available elevation change, check the Assessment Processes below.

Under the right circumstances, a micro hydropower project can be operated with as little as 5 feet of elevation change. For such a system to work, the elevation change needs to be instantaneous and cannot be stretched out at all. The use of a stilling chamber or forebay might be needed.

If you site has less than 5 feet, you can consider in-stream (hydrokinetic) micro hydropower.

Is your site's stream flow more than 25 cubic feet per second (CFS)?

To assess the available Mean Flow [cfs], check the Assessment Processes below.

[3] Land under non-navigable bodies of water is presumed to be owned by the abutting owners to the center line of the body of water. https://caselaw.findlaw.com/ny-court-of-appeals/1508022.html

[4] An easement is a limited right to use another person's land for a stated purpose. https://www.justia.com/real-estate/docs/easements/

[5] http://www.dec.ny.gov/lands/4991.html

A mean flow of less than 25 cfs means there might not be enough flow during the drier months of the year to fully operate the micro hydropower project. Small amounts of energy might still be generated, though.

You might consider a pico-hydropower facility.

Is the expected power potential more than 5 kilowatts (kW)?

Hydropower systems less than 5 kW can be considered pico hydropower. To make these systems work financially, the necessary inputs for equipment and site alteration have to be minimal. A 5 kW system can have an expected energy output of about 22,000 kWh annually – easily enough for multiple energy efficient homes. A combination with battery back-up systems is possible.

Is the Power Potential divided by the Intake-Outlet-Distance more than 1 kW / 10 feet?

Combining two of our assessment results, i.e. the Power Output [kW] and the Intake-Outlet-Distance, allows us to calculate the relative power potential per bypass reach distance. Divide the Power Potential by the Intake-Outlet-Distance and compare the result to our guidance value of 1 kW / 10 ft. or 0.1kW/ft. respectively. To minimize local environmental impacts, this ratio should be as high as possible and is more easily reached for larger, high-head micro hydropower systems than smaller low-head systems.

Specific site parameters can still lead to the decision to implement a system with a ratio of less than 0.1 kW/ft. These parameters can be the environmental and topographic setting of the site, existing infrastructure and other synergies with existing or planned structures.

Is installing the intake structure dependent on significant alteration of the dam?

Significant alterations of the dam, e.g. cutting out parts of the dam to install an intake structure, can have impacts on the stability and structural integrity of the dam. Costly assessments, hydraulic load modelling and the actual work might make a micro hydropower project financially infeasible.

Ideally your dam has an existing intake structure (that either can be used or can be upgraded) or you find a way to bypass the dam by installing an intake structure somewhere in the impoundment or in adjacent existing structures. These methods allow you to have an intake without impacting the dam's stability.

Is there space at the bottom of the waterfall for a structure to house the equipment?

Even where there is no dam influencing flood events, flood events still do happen. All equipment placed in the vicinity of the stream needs to be protected from floods coming down the waterfall. The larger the proposed power output, the larger the necessary turbine and generating equipment, the larger the powerhouse structure required to protect it all. There are technologies that can be fully submerged, but none the less, space is needed to place the equipment near the stream. If the topographic parameters do not allow for the equipment to be placed at the necessary location (e.g. stream flowing through a canyon), consider a smaller system that takes up less space.

Is the dam classified as Hazard Class C?

Class C dams are high hazard dams, for which failure is likely to result in loss of life. To ensure that Class C dams don't fail, the assessment and reporting requirements are significant, as can the maintenance cost associated with the upkeep. A hydropower system on a Class C dam needs to significantly larger than “micro” to generate enough revenue to make that a financially sustainable project.

Is the dam classified as Hazard Class B?

Class B dams are right at the border of feasible and infeasible for a micro hydropower system. Depending on the size of the project or other external factors that make such a system financially sustainable, a Class B dam might be developed for a micro hydropower project. The recommendation remains to primarily consider Class A and dams without hazard class for hydropower development.

Is your dam in poor condition?

A dam in poor condition is not the right location for a new micro hydropower system. Repairing and rehabilitating such a dam is likely expensive and might outweigh any financial benefit created by electricity generation. Asses your Dam Condition; if your dam suffers from significant seepage through or underneath your dam, shows significant signs of erosion and spalling you should consider dam removal as the alternative course of action.

The only exception to this recommendation is if the dam has other useful purposes and would need to be repaired anyways – in which case combining the rehabilitation with simultaneously installing a micro hydropower system makes a lot of sense. If this applies to your dam, continue in the flowchart, but see: *Consider Financial Impact*.

Does your dam need repairs / to be rehabilitated?

A professional engineering assessment of your dam will give you an exact list of all observed deficiencies and how they can be corrected. But some aspects of the Dam Condition can be assessed by the dam owners themselves. If you think your dam needs repairs or to be rehabilitated in some form or another, consider if these repairs can be combined with the necessary alterations for adding the micro hydropower system. See: *Consider Financial Impact*.

Repairing a dam is the alternative to dam removal. Waiting for the dam to deteriorate and fall apart is never the recommended path of action.

Can your dam safely pass the Spillway Design Flood (SDF)

Once you’ve assessed your dam’s Spillway Dimensions, you will know if your dam can pass the Spillway Design Flood. In cases where the spillway is slightly undersized, widening the spillway might be an option; parts of the training walls adjacent to the spillway will be cut off and thus widen the spillway. The benefit of doing so is that the dam becomes more climate resilient as projections for north-eastern United States predict increased precipitation with more severe rain events in the coming decades. See: *Consider Financial Impact* (of spillway widening).

Note: Some dams are designed to be overtopped, in which case the Spillway Dimensions calculation will result in a significantly undersized spillway.

Unless your dam can pass the spillway design flood, consult your regional dam safety department of the DEC and consult with local engineering firms specializing in concrete and in-water construction.

Is the expected energy generation larger than the on-site or near-site consumption?

Based on Energy Generation [kWh] and Energy Consumption [kWh], which of the two is larger? In the ideal (grid-connected) case your Energy Consumption [kWh] should be about equal to your Energy Generation [kWh] – In an off-grid case you want your generation to outperform your consumption.

The difficulty in answering this question comes from the definitions of on-site and near-site consumption. On-site consumption includes all buildings and structures that are already connected to the property's utility meter (if any) plus any planned structures and their consumption.

Is grid connection feasible?

Looking at potential Offtakers for your electricity, you might need to look beyond the project property. There are multiple ways of selling your electricity to other utility customers or even use it on your own remotely located properties. But a grid connection is needed, and this connection should be rather close to the project site. The larger the Power Output [kW], the further away the next power line can be. Small systems need the grid connection closer, but smaller lines might then also be sufficient. If you're unsure about the information provided online, talk to your utility to confirm whether grid connection is feasible.

Do you own other properties in the area that could use the energy?

Using *Consider Remote Net-Metering*, it is possible to also supply your other properties within the same utility with your own hydropower (located on another property that you own). The utility meters on all properties need to be in the same name.

Is there a large energy user in the vicinity that might be interested in purchasing your energy?

If Energy Generation [kWh] is still significantly larger than your combined consumption, consider looking at possible consumers on neighboring properties, especially if direct wiring of those neighbors to the micro hydropower facility is a possibility. *Consider Power Purchase Agreement* with that neighbor and selling your electricity directly to them.

Are you interested in operating your micro hydropower project as a business?

If your Energy Generation [kWh] is significantly larger than your Energy Consumption [kWh], *Consider Community Distributed Generation* (CDG) scheme. It allows you to sell your energy to other utility customers in your community. You will be in charge of marketing and billing your customers and organizing the CDG. Instead of just generating your own renewable energy you will be helping your community to become greener.

Assessment Processes

Elevation Change [measured in feet]

One of the key factors in sizing a micro hydropower system is the (net) head. The (net) head is the usable elevation change between the upstream water level at the intake and the downstream water level at the outlet, minus losses (friction of piping, inlet and outlet structures, etc.). These losses are higher if the distance between intake and outlet location increases, that means the ideal micro hydropower system bypasses the minimal stream distance and keeps the outlet as close as possible to the intake (e.g. intake at dam and outlet right below the dam). If additional elevation change is gained by moving the outlet further downstream (additional rapids or waterfalls downstream of the dam) it might make sense to do so.

The first step of measuring the elevation change is picking the possible location of the intake and the outlet structures. Depending on the distance between these locations, we propose you use the direct measurement approach (Figure 1). Using this approach, you will work your way stepwise from the upstream location towards the possible outlet locations. The starting point, in systems that involve a dam, is the elevation of the spillway[6] which will be the minimum top elevation / impoundment elevation. The scenario in Figure 1 shows a two-step measurement from the impoundment water level to the water level under h2. The total elevation change would be h1 + h2. Depending on the distance between inlet and outlet, measuring the elevation change can be 10 or even more steps. How far apart the individual step are from each other, depends on the kind of equipment that is available to you.

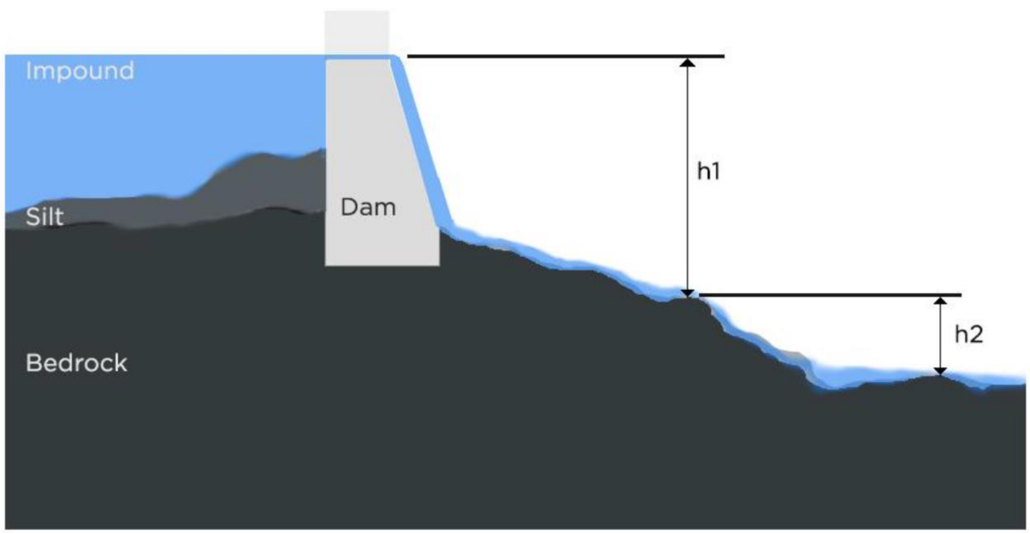


Figure 1 - Direct Measurement Approach for Elevation Changes

The best way to manually measure elevation changes is by using a laser level on a tripod. Other helpful utensils can be painter's blue tape, a manual level, a measuring tape and something to take notes with. Especially when the distance between intake and outlet is only a couple of feet, a couple of 2-by-4s might do just fine.

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[6] **SPILLWAY**: A structure over or through which flows are discharged. In many instances, the spillway is lower than the rest of the dam height.

The same exact approach can be taken for waterfalls, to assess the elevation change at sites where there is no dam.

Mean Flow [measured in cfs]

Estimating the mean flow can be done online. The United States Geological Service (USGS) offers an online tool named StreamStats[7]:

1. Zoom into the area of interest on the map via the mouse wheel or the +/- button on the upper left. At zoom level 8 (see zoom level on the lower left corner) you will be able to select your State/Region.
2. On the left panel, click on your State. Then zoom into level 15 or greater to enable the delineation tool.
3. On the left panel, click on “Delineate” and then click on a point on the map that shows a blue-pixel stream line. This point should roughly match the location of your planned intake structure (dam, top of the waterfall, location in stream). Clicking on a valid point will start the delineation process.
4. Goal of the delineation process is to calculate the drainage basin / watershed[8] that drains into the location you chose in step number 3. An example of the current output is shown in Figure 2. Generally, the further downstream you go, the larger the drainage basin, as more land is draining into that specific location. Press on continue on the left panel.
5. Chose Regression Based Scenarios: click on all offered scenarios and then click continue below. The system will now calculate the basin characteristics
6. Select all available reports to display and press continue below. The report will open in the middle of the screen – you can print (or pdf-save) this report for your own documentation.
7. The main parameter we’re interested in is named DRNAREA, the area that drains to our selected point on our stream. The displayed value is measured in square miles and an indicator for the amount of flow we can expect.
8. A very basic rule of thumb is that the mean available flow in cubic feet per second (cfs) is about 1.5 times the drainage area in square miles (DRNAREA). A more detailed approach is offered by Dudley (2004)[9]. For the 26 square miles drainage area in Figure 2, the estimated mean available flow would be 39 cubic feet per second (cfs).
9. Save the report as pdf for future reference (e.g. to assess the Spillway Dimensions).

Depending on the distance between intake and outlet and the thereby created stream bypass, it is the project owner’s responsibility to ensure aquatic life can survive despite the operation of the micro hydropower system. The available mean flow has therefore to be adjusted by a certain amount that has to remain in the stream at all times: the environmental flow. Factors like the width and depth of the main stream channel define the necessary environmental flow. For estimates this value can be as little as 4 cfs (in smaller streams) and up to 0.5 cfs per square mile of drainage area (DRNAREA).

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[7] StreamStats is a Web-based Geographic Information Systems (GIS) application that provides users with access to an assortment of analytical tools that are useful for a variety of water-resources planning and management purposes, and for engineering and design purposes. See https://streamstats.usgs.gov/ss/

[8] **WATERSHED**: The land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean. https://oceanservice.noaa.gov/facts/watershed.html

[9] Dudley, R.W., 2004, Estimating monthly, annual, and low 7-day, 10-year streamflows for ungaged rivers in Maine: U.S. Geological Survey Scientific Investigations Report 2004-5026, 22 p, accessible under: https://pubs.usgs.gov/sir/2004/5026/pdf/sir2004-5026.pdf

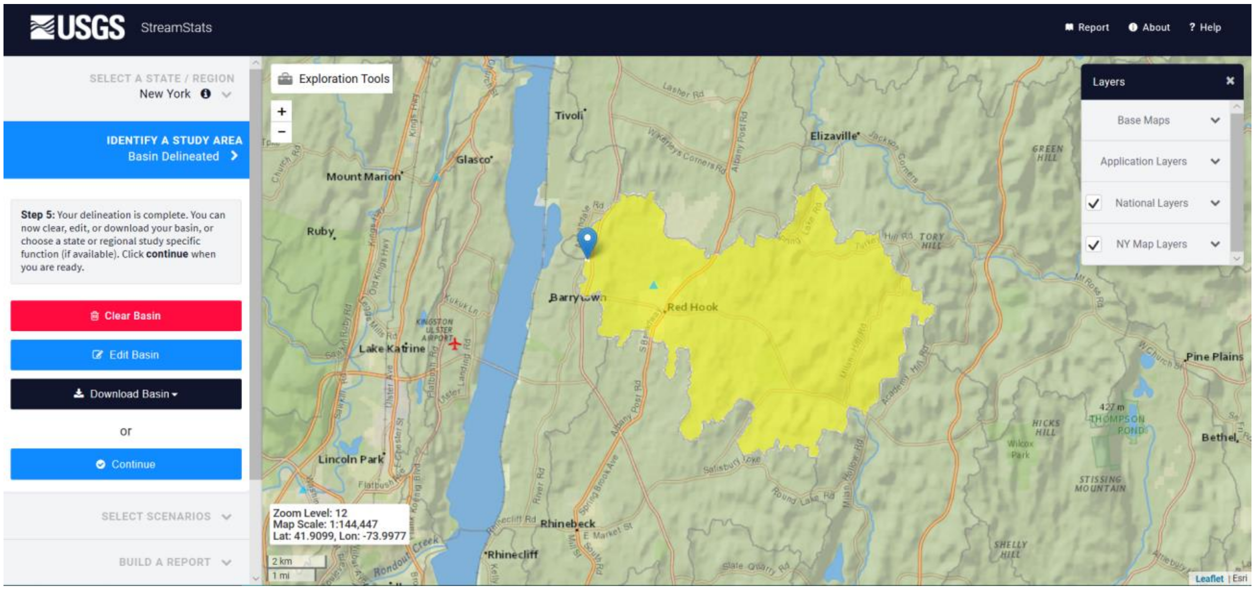

Figure 2 - Example of watershed draining into one specific location

<u>For non-powered dams</u>, the (usable) mean flow is the available mean flow minus the environmental flow. For dam-free sites, the (usable) mean flow is a fraction of the available mean flow, as any possible intake structure (for technical reasons) will likely only collect a share of the waterfall's flow – a special case to this assumption are waterfalls that have a lake right above them, where a flow-controllable intake structure can be installed.

Power Output [measured in kW]

In SI units the power formula can be as simple as:

$$Head\ [m]\ x\ Flow\ [m^3/s]\ x\ 9.8$$

1 foot = 0.3048 meters and 1 cfs = 1 cubic foot = 0.0283 cubic meters, turning the formula into:

$$Head\ [ft.]\ x\ Flow\ [cfs]\ /\ 11.8$$

As all mechanical and electrical systems, the micro hydropower system will contain certain inefficiencies. These include losses in the wiring, a gearing system, voltage transformation, losses in penstock and intake structures, or turbine and generator losses. Depending on system size and design, overall system efficiency may range from 50% to 80%. The overall power output therefore needs to be adjusted by a factor within those two values. Low-key systems with a large distance between intake and outlet structure tend to be less efficient, than larger systems with almost no piping. Choose 65% as a very rough estimate. Calculators that offer more detailed formulas and more information on system efficiencies can be found online.[10]

Intake-Outlet-Distance [ft.]

The Inlet-Outlet-Distance is a key parameter in the design of a micro hydropower system. Larger elevation changes might be realized by locating the outlet further downstream. The problem with this is

[10] For example, see https://power-calculation.com/hydroelectricity-energy-calculator.php or https://www.engineeringtoolbox.com/hydropower-d_1359.html

the increased penstock losses within the piping necessary to convey the water from the intake location. To reduce these losses the pipe diameter can be increased, leading to overall higher material and installation cost as well as local site-impacts (excavation, cranes, access road, …).

Increasing this distance also impacts the local stream ecology, as moving the outlet further downstream also increases the stream length that is being bypassed by the piping system. Especially in the low-flow summer months these environmental considerations need to be taken into account.

In short, an increased Intake-Outlet-Distance increases the overall complexity of the micro hydropower endeavor and should be justified by a significant gain in elevation change (head) and power output. As a rule of thumb, every micro hydropower system should at least generate one 1 kW per every 10 feet of bypassed stream distance.

Existing Infrastructure

Existing infrastructure can be a valuable commodity when it comes to micro hydropower. Document all existing components and assess their dimensions and condition (good, okay, poor).[11] These components might include:

- Intake structure;
- Intake screen;
- Piping, channels or bypasses;
- Gates and valves;
- Turbines, waterwheels, and generators;
- Buildings, chambers, electrical panels or powerhouses;
- Electric lines, poles, transformers and other electrical equipment;
- Outlet structures, channels or draft tubes; etc.

As every hydropower system will need a screened intake structure, a turbine-generator system, an outlet and an electrical connection of some kind, every piece of equipment that is already in place will simplify the project. This is true especially for existing pipes or channels that bypass/pass the dam, as the best micro hydropower installation is one where dam alterations aren’t necessary. Existing pipes can be relined and made usable again, but they also limit the hydropower potential to the existing pipe diameter.

Dam's Hazard Class

The downstream hazard classifications (short Dam Hazard Class) are defined in 6 NYCRR Subpart 673.5(b) and classify dams into three categories:

- (1) Class "A" or "Low Hazard" dam: A dam failure is unlikely to result in damage to anything more than isolated or unoccupied buildings, undeveloped lands, minor roads such as town or county roads; is unlikely to result in the interruption of important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; and/or is otherwise unlikely to pose the threat of personal injury, substantial economic loss or substantial environmental damage.

[11] This assessment step might be of a lesser relevance to undeveloped sites at a waterfall.

- (2) Class "B" or "Intermediate Hazard" dam: A dam failure may result in damage to isolated homes, main highways, and minor railroads; may result in the interruption of important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; and/or is otherwise likely to pose the threat of personal injury and/or substantial economic loss or substantial environmental damage. Loss of human life is not expected.
- (3) Class "C" or "High Hazard" dam: A dam failure may result in widespread or serious damage to home(s); damage to main highways, industrial or commercial buildings, railroads, and/or important utilities, including water supply, sewage treatment, fuel, power, cable or telephone infrastructure; or substantial environmental damage; such that the loss of human life or widespread substantial economic loss is likely.

You can find out the hazard class rating of your dam via the National Inventory of Dams[12] where you can search for your dam under "Interactive Maps & Charts". If you cannot find your dam and have never received a letter from the NYS Department of Environmental Conservation Dam Safety department, your dam might not be rated – either public entities don't know it exists or its rating is less than A.

Dam Condition

The physical condition of your dam is one crucial factor within the decision-making process: A dam that is likely to fail within the decade is not worth investing in without repairing the dam first. But not every little leak or trickle means a dam is in a bad condition. After all, most dams are centuries old and a little trickle here and there is very normal - assess your dam to evaluate its condition.[13]

The goal of this assessment is to get a sense of existing deficiencies and their severity. At the very least it is important for a dam owner to regularly document and photograph these deficiencies to make sure they are not worsening. To do that, take pictures of every deficiency you find and describe the location, size and other visible indicators for each of them; if you can, speculate about the cause of the deficiency.

To help you navigate this assessment, consult the following table, which contains common dam deficiencies and how they relate to a possible micro hydropower installation.

Table 1 - Dam Condition: Common deficiencies of historic dams

1. Large trees growing near the toe of the concrete dam face	See Dam's Surroundings
2. Stumps of large trees in the embankment upstream of the concrete dam face.	See Dam's Surroundings
3. Debris washed up on spillway crest and/or at the toe of the dam.	Does not impede micro hydropower installation. Safely remove debris if you can to allow maximum flow over the spillway.

[12] nid.sec.usace.army.mil
[13] This self-assessment of the dam's condition does not satisfy oversight requirements by state and federal agencies, nor is it a substitute for a proper dam engineering assessment conducted by a licensed engineer.

4. Soil loss along the toe of the dam (where the dam meets the ground) and along the back face of the dam. This can happen from floodwaters overtopping the dam and eroding upstream embankment soils.	Does not impede micro hydropower installation Depending on the dam type, overtopping can be a common function to convey floods Soil loss and erosion should be addressed and downstream area should be stabilized
5. Low areas constituting loss of contact at both abutments of the dam (where the concrete/stone masonry dam structure ends). These low areas would allow concentrated flows during very high water and could lead to unravelling/erosion of the dam and or abutment soils initiating at those locations.	Does not impede micro hydropower installation. Flows bypassing the dam can lead to erosion of the dam and should be fixed Contact areas need to be stabilized
6. Upstream embankment vegetated with brushy vegetation.	See Dam's Surroundings
7. Extensive cracks and leaks in the downstream face of the dam. Evidence of seepage through these cracks can include visible flowing seepage, visible water pooled at toe of dam, soft soils at toe of dam, and moss growing on downstream face of dam.	See below
8. Spalled and delaminated concrete.	See below
9. Large voids in the downstream concrete face of the dam.	See below.
10. Voids at the base of the training walls; training walls undermining due to erosive flow.	See below.
11. Non-functioning low-level outlet.	This is a critical deficiency. Micro hydropower installation in many instances requires upstream work from within the impoundment. The low-level outlet needs to be operable to lower the impoundment water level to allow installation. The alternative is using external pumps to lower the impoundment – a very cost intensive effort. The low-level outlet is further needed to allow proper dam inspection and maintenance; depending on the dam's hazard class, regular inspection is a requirement.

With regard to deficiencies numbers 7 – 11 from above table, the following examples demonstrate minor leaks, spalling, voids and cracks. But even minor leaks should be fixed sooner than later, as water flowing through the dam (even a trickle) will only be getting worse over time.

Example 1: Undermining and spalling of training wall

Years of flow and debris can undermine the training walls on either side of a spillway. Figure 3 is a close up of such undermining and shows the spillway on the left of the image and the training wall to the right. Also visible is smaller pieces of debris stuck in the hole.

Figure 3 - Example of Undermining and Spallilng of Training Wall (I)[14]

Figure 4 shows even more severe spalling and undermining, with the spillway on the right and training wall to the left.

Figure 4 - Example of Undermining and Spalling of Training Wall (II) [15]

[14] Picture taken from Fuss & O'Neill (2018). NYSDEC Dam Safety Supplemental Engineering Assessment, Annandale Dam.

[15] Picture taken from Fuss & O'Neill (2018). NYSDEC Dam Safety Supplemental Engineering Assessment,

In both instances, repairs are relatively easy during low flow season. A simple wood structure made from plywood and 2-by-4s can serve as formwork to fix the spalling. The sooner these issues get repaired, the less work it is.

Example 2: Cracks, Crumbling and Open Joints

Figure 5 shows a deficiency that is caused by the way this dam was built (rebuilt) in the past. Below the crack is the historic dam, above the crack one can see an addition that was installed later on. The seam between the two layers drips water keeping the lower part constantly moist and leading to moss growth and erosion of concrete.

Figure 5 - Example of Crumbling and Open Joints[16]

Figure 6 shows efflorescent cracks in the dam face and seepage through cracks. The depression beneath can indicate poor contact, likely caused by water flow overtopping the dam.

Figure 6 - Cracks[17]

Annandale Dam.

[16] Picture taken from Fuss & O'Neill (2018). NYSDEC Dam Safety Supplemental Engineering Assessment, Annandale Dam.

[17] Picture taken from Fuss & O'Neill (2018). NYSDEC Dam Safety Supplemental Engineering Assessment,

Many of these deficiencies (depending on severity) can be fixed cost-efficiently if access to the upstream side of the dam is possible, i.e. if the impound can be drained for maintenance and repairs. The Ohio Department of Natural Resources explains different concrete repair techniques and other dam safety measurements in their Fact Sheets collection.[18]

Spillway Dimensions

New York Department of Environmental Conservation's 1989 publication Guidelines for Design of Dams[19] (which is also the source for the figure below) specifies the spillway capacity for dams that are being rehabilitated depending on the dam's hazard classification (see Dam's Hazard Class). The Spillway Design Flood (SDF) is the largest flow that a given project is designed to pass safely.

According to Figure 7, dams that are being rehabilitated (and have only a single spillway) are required to have adequate spillway capacity to pass a spillway design flood (SDF) equivalent to 100% of the 100-year flood without overtopping (for Class A dams), 150% of the 100-year flood without overtopping (for Class B dams) and 50% of the Probable Maximum Flood[20].

5.3 Existing Dams - Design Flood

Existing dams that are being rehabilitated should have adequate spillway capacity to pass the following floods without overtopping:

Hazard Classification	Spillway Design Flood (SDF)
A	100 year
B	150% of 100 year
C	50% of PMF

Figure 7 - Spillway Design Flood Requirements

The goal of the spillway dimensions assessment is to verify that the existing spillway meets those criteria, in case the micro hydropower installation requires some form of dam rehabilitation.

To calculate a dam's spillway capacity use the broad crested weir equation as follows:

$$Q = CLH^{\frac{3}{2}}$$

where:

Q = discharge through the spillway
C = discharge coefficient (varies between 2.6 and 3.5; assume 3.0)[21]
L = length of the spillway
H = depth of water over the spillway, determined by the height of the training walls

Annandale Dam.

[18] Ohio Department of Natural Resources Division of Water Fact Sheet Collection, accessed 01/07/2020 from: https://damsafety.org/sites/default/files/files/Ohio%20Department%20of%20Natural%20Resourses%20-%20Division%20of%20Water%20Fact%20Sheets_0.pdf

[19] The document can be found online: https://www.dec.ny.gov/docs/water_pdf/damguideli.pdf

[20] Probable Maximum Flood (PMF) is the flood that can be expected from the severest combination of critical meteorologic and hydrologic conditions possible for the particular region. It is the flow resulting from the PMP.

[21] Figure 3 of USGS's GEOLOGICAL SURVEY CIRCULAR 397 from 1957 displays the discharge coefficients for broad-crested weirs with vertical faces and horizontal crest square entrance. See https://pubs.usgs.gov/circ/1957/0397/report.pdf

Figure 8 offers a simple calculation example with a 60-foot spillway and 4-foot training walls. Using a discharge coefficient of 3.0, the resulting spillway capacity is 1,440 cfs.

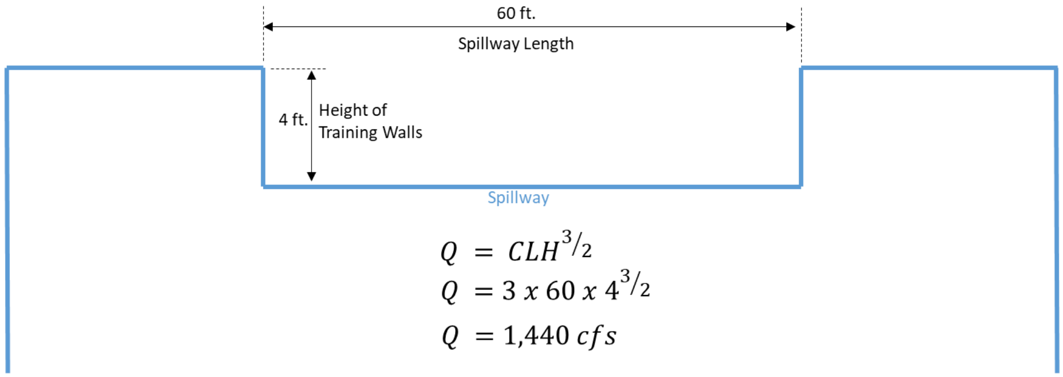

Figure 8 - Calculation Example: Spillway Capacity

The final step of this assessment is to compare the calculated spillway capacity with the expected 100 year flood of your watershed at your site. To find an estimate for your flood probabilities, open the StreamStats report you created to estimate the Mean Flow [cfs]. That report contains a section titled "Peak-Flow Statistics Flow Report" (see Figure 9 for an example) and shows the expected flood flows for the respective flood-events.[22]

Peak-Flow Statistics Flow Report [2006 Full Region 2]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	SEp	Equiv. Yrs.
1.25 Year Peak Flood	381	ft^3/s	25.5	25.5	4.8
1.5 Year Peak Flood	459	ft^3/s	25.6	25.6	4.3
2 Year Peak Flood	571	ft^3/s	25.8	25.8	4.4
5 Year Peak Flood	916	ft^3/s	27	27	7.3
10 Year Peak Flood	1210	ft^3/s	28.2	28.2	10.1
25 Year Peak Flood	1650	ft^3/s	29.9	29.9	13.6
50 Year Peak Flood	2040	ft^3/s	31.5	31.5	15.8
100 Year Peak Flood	2470	ft^3/s	33.3	33.3	17.6
200 Year Peak Flood	2950	ft^3/s	35.3	35.3	18.9
500 Year Peak Flood	3690	ft^3/s	38.4	38.4	20.1

Figure 9 - Example StreamStats Peak-Flow Statistics Flow Report

In this example the 100 year peak flood flow value is 2,470 cfs. Based on above calculation the example dam can safely convey only 1,440 cfs (58% of the 100 year flood). If this example dam was a Class B dam,

[22] For reference: The 100 year flood has a 1% chance, the 10 year flood has a 10% chance and the 2 year flood has a 50% chance to occur in any given year. The higher the flood-year the lower the chance this specific flood flow will occur.

the requirement was to convey 150% of the 100 year flood – in this case 3,705 cfs, reducing the capacity to only 39% of the required spillway design flood.

To rehabilitate this dam, the dam safety department might require a widening of the spillway, which can be expensive.

Dam's Surroundings

A well-maintained dam is also located in a well-maintained area. The following table discusses common deficiencies of a dam's surrounding and their impact on the dam's condition.

Table 2 - Dam Surroundings: Maintenance Suggestions near the Dam

1. Large trees growing near the toe of the concrete dam face	Trees within 20 feet of the dam, might grow roots through and into the dam's structure (even in concrete dams) Removing those trees is recommended. Don't rip out roots that dug into the dam structure.
2. Stumps of large trees in the embankment upstream of the concrete dam face	Large tree stumps near the dam indicate the potential of roots already dug into the dam structure Don't rip out those roots.
3. Upstream embankment vegetated with brushy vegetation	Roots might damage dam structure (even in concrete dams).
4. Debris washed up on spillway crest and/or at toe of dam near right training wall	Washed up debris can alter the water flow direction and lead to erosion.
5. Signs of groundhogs or other burrowing animals in the vicinity of the dam	Animals might burrow holes near the dam, offering the water an additional attack point during floods, potentially leading to significant erosion.

Energy Generation [measured in kilowatt-hours (kWh)]

To conservatively assess the energy generation potential, one has to multiply the micro hydropower system capacity in kW by the numbers of hours per year that the system will operate. As the system likely will not operate at full capacity throughout the whole year (i.e. low flow in summer), one also has to include the so called capacity factor, which describes the percentage of the time the system is running at full capacity.

$$Energy\ [kWh] = Power[kW] x\ Hours\ of\ Operation\ [h]\ x\ Capacity\ Factor\ [\%]$$

A year has 8,760 hours (24 hours a day x 365 days a year), and the system could potentially run continuously (neglecting maintenance and repair time). The capacity factor mainly depends on the system design and at what flow the system reaches its 100% power output. A smaller system at the same stream as a larger system, is less likely to suffer from low flow in the summer and reaches its full power output earlier. Conservatively use 60% capacity factor for your calculation, unless you know your stream's flow duration curve and can predict the capacity factor more precisely.

Example: With 8,760 hours in a year, an assumed 20 kW micro hydropower system with a 60% capacity factor will generate about 105,120 kWh per year:

$$Energy\ [kWh] = 20\ [kW] x\ 8{,}760\ [h]\ x\ 60\ [\%] =\ 105{,}120\ kWh$$

The amount of energy generated is an important number to know. It defines the financial viability by telling you how much energy your micro hydropower system will be offsetting fossil fuel generation, either at your own meter and/or at your neighbor's meter.

This number can also be an indicator for you to design a smaller system if there is no alternative use for the energy then your own consumption, and generation is much larger than your consumption. A smaller system with a higher capacity factor might end up being more cost efficient if there is no other use for the energy.

Offtakers

Generating renewable energy will only have positive effects if that energy is being used. These users or offtakers can be buildings and structures on site, depending on the setting, private residences or commercial operations, farms and barns or municipal buildings. The goal of this assessment is to create a list of possible offtakers, their energy and power needs and how far away they are from the micro hydropower project.

Dams that historically were used for milling purposes might still have an old mill building in direct vicinity of the dam and the potential micro hydropower system. If that building is currently inhabited, there will likely be a connection with the electric utility grid which then can also allow for the micro hydropower system to export energy to the grid. The grid itself can also count as an offtaker as excess energy can be shared with the grid and/or be sold to other electric customers in the vicinity.

Also, neighboring properties might be possible offtakers for the energy.

The information about the offtakers will influence the decision towards a marketing/offtaker model for you micro hydropower project, and whether you will use the energy directly, off-gird, via remote net-metering or via a community distributed generation scheme. See Actions, Recommendations and for more information and follow the flowchart.

Please assess the following:

- Your Energy Consumption [kWh];

- Check if there is large energy consumption near the planned micro hydropower site that does not belong you. Business and other commercial operation might be interested in switching to all renewable energy supply and might use more energy than your own property;

- If there is no or not enough energy use on the project-property consider exporting energy via the electric utility grid:

- Using a map, measure the distance from the potential micro hydropower project to the nearest point of interconnection. In most cases that might be the electric meter of the building on the property of the project site. A short distance to the grid makes interconnection easier and more cost-effective.[23]
- Use your utility map and collect information about the closest electric utility line, like number of phases, voltage and hosting capacity. This is important because small (single phase, low voltage) electric lines in remote areas might limit the maximum amount of energy that can be exported to the grid;[24]

- Consider future plans for additional energy users in the vicinity (new buildings, new businesses, etc.)

If there is not enough energy use for your Energy Generation [kWh], consider downsizing your micro hydropower system plans accordingly (go back to Start). If there are no potential offtakers at all, a system might not be feasible.

Energy Consumption [kWh]

You will need to assess your annual energy needs as part of the system design. If your energy needs are greater than your micro hydropower output, you will need additional power sources (other renewable energy sources, or the electric grid). Or, depending on by how much your generation exceeds your consumption, you can either (I) install an additional battery system to store energy (Consider Off-Grid), (II) provide energy to a single larger offtaker (Consider Power Purchase Agreement) or (III) provide electricity to other members of your community (Consider Community Distributed Generation).

When you assess your energy consumption, you can assess the current energy consumption and future energy consumption. Future energy consumption looks at future appliances, their energy needs and how you will use them (use pattern). The current energy consumption can easily be assessed by looking at your monthly utility bills. Your monthly bills add up to your annual energy consumption and can also show you seasonal consumption patterns throughout the year.

Peak Power Usage [kW]

The peak power usage is an important value if you are Consider Off-Grid . The micro hydropower system will need to be able to provide enough power to run your appliances and devices according to your use pattern. For each and every device you own, you will need to assess the power usage on an hourly basis – for every day of the week – based on your family's behavior. When people come home from work they might turn on the TV, while using the microwave, while running the dishwasher and having multiple

[23] Transporting electricity over long distances creates transmission losses. The relationship between transmission distance, wire / cable diameter and transmission voltage defines the amount of losses; increasing the voltage as well as increasing the wire diameter reduces the losses, while increasing the transmission distance increases the losses. But increasing the voltage (using additional transformers) and increasing the wire diameter also increase project cost and therefore making it necessary to find the right balance transmission distance and project costs. Smaller systems want to be as close as possible to the grid / the location of energy usage.

[24] Many utilities offer online maps of their grid, to allow developers of renewable energy generation to place their systems in favorable locations. These maps can be called "system indicator map" or "hosting capacity map" and they contain information about the voltage, number of phases, minimum and maximum local hosting capacity values, interconnected and proposed DG in queue, NYISO Load Zone, as well as DG installed since last hosting capacity refresh. Example: Central Hudson's Hosting Capacity Map: https://www.cenhud.com/my-energy/distributed-generation/hosting-capacity-map/

Every utility handles this type of information differently, so we recommend checking their websites and reaching out to them with questions. Single phase systems are more restricted than three-phase lines; single phase lines can max out around 25 kW to 50 kW and upgrading the electric grid to three-phase is in most cases not a financially viable option.

lights on – creating a peak consumption hour. The summer peak consumption (air-conditioning) might be different from the winter peak consumption (space heaters, lights, …). But the peak consumption is what defines the minimum size for our micro hydropower system.

You can use a plug power meter (also called a watt meter or electricity usage monitor) which you can buy online for as little $20. You will plug the meter between the outlet and the device you are assessing, and the meter's display will show you the voltage, ampere and power that that specific device is currently using. Note: Washing machines, dryers, dishwashers, fans and other appliances have different programs and settings in which they might use different amounts of power and energy.

An example of such a plug power meter and its usage can be seen in Figure 10.

Figure 10 - Visual demonstration of example plug power meter use[25]

For lights and other hard-wired devices refer to the markings on the product or the product manual (e.g. the wattage of light bulbs).

Turbine Technology

Figure 11 shows different turbine technologies and their operating ranges; shown technologies might operate less efficient under parameters closer to the edges of respective technology's area. Compare

[25] Alteration of Image from P3 P4400 Kill A Watt Electricity Usage Monitor, https://images-na.ssl-images-amazon.com/images/I/61XZGr66kdL._SL1500_.jpg Note: this is not a product recommendation.

the calculated Elevation Change (Head) and the Mean Flow with the figure to choose a turbine technology.

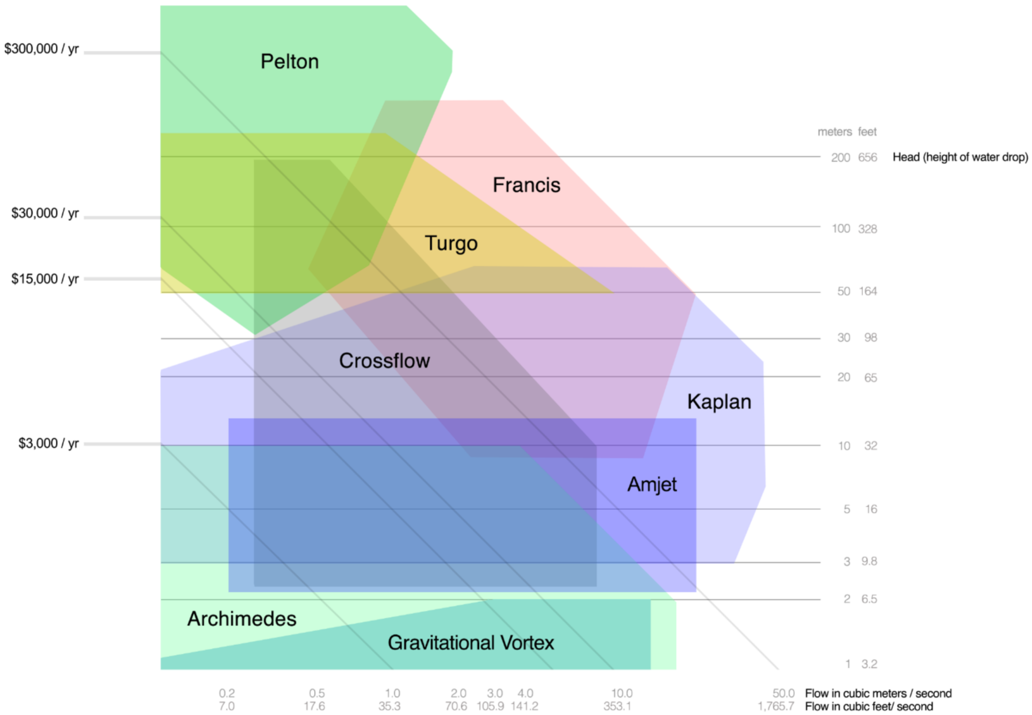

Figure 11 – Micro Hydropower Turbine Technologies

The name of the turbine type will help you search for suppliers and vendors for your system.

When using this chart consider that you can use multiple units to extend the operating range of the shown values. Example: A single Gravitational Vortex has a maximum head of 6.5 feet, but you will be able to connect two Gravitation Vortex units in series using the outflow of the first unit as the inlet to the second unit (located further below). That way you can make two GV units work 13 ft. of head.

Actions, Recommendations and Considerations

Start

As mentioned earlier, there are two different flowcharts depending on your specific starting point: If you own a dam that you would like to upgrade to a micro hydropower project, use **Non-powered Dam Micro hydropower Decision-Making Framework**. If you do not own a dam, but want to make use of a natural waterfall, to generate electricity, use **Dam-Free Micro hydropower Decision-Making Framework**.

Micro-Hydro likely not possible

If you've reached this point, it seems like your site is not a good candidate for a micro hydropower installation. Dam condition, flow and head availability and other factors may be the cause for this determination.

Assess Micro-Hydro Power Potential

To assess your micro-hydro power potential you will need to gather information about

- Elevation Change [feet];
- Mean Flow [cfs];
- Power Output [kW];
- Intake-Outlet-Distance [ft.];
- Existing Infrastructure.

Details about how to do these assessments can be found in the relevant section of the *Assessment Processes*. Continue with the flowchart once you've collected the requested information.

Consider Pico-Hydro

It seems like your site is too small for a standard micro hydropower project. But the good news is, there are turbine-generator designs out there for very small systems – so called pico-hydropower. Pico-hydropower is in the scale of a couple hundred watts and the systems are mostly made from plastic components. They are not designed for multiple decades of operation but their requirements are respectively low.

Consider Alternative Design

The best design involves as little as possible changes to the existing site. Every change, every alteration needs planning, permitting and is associated with additional cost. Using existing infrastructure is thus recommended. But sometimes there are other options that better suit the needs of the site than the most obvious or historic solution.

Simpler systems, despite potentially lower energy output, might be preferable and thus should be considered. See: *Consider Financial Impact* (when making design decisions).

Consider Financial Impact

As is figuring out how to not alter the dam at all (e.g. by bypassing the dam, instead of going through the dam), even if it means an overall lower head and power output. The reason for this is that the financial viability of every micro hydropower project depends on the payback period, simply defined as:

$$Simple\ Payback\ [year] = \frac{Initial\ Capital\ Investment\ [\$]}{Energy\ Output\ \left[\frac{kWh}{year}\right]\ x\ Price\ per\ kWh\ \left[\frac{\$}{kWh}\right] - O\&M\ Cost\ [\frac{\$}{year}]}$$

In order to minimize the payback period the micro hydropower design needs to be optimized towards having a minimal initial capital investment and a maximum energy output. A simpler design might reduce the initial capital investment as well as the operations- and maintenance (O&M) cost, potentially reducing the payback period compared to a more complex system with a higher energy output.

Assess Dam Condition

To assess your dam condition you will need to gather information about:

- Dam's Hazard Class
- Dam Condition
- Spillway Dimensions
- Dam's Surroundings

Details about how to do these assessments can be found in the relevant section of the *Assessment Processes*. Continue with the flowchart once you've collected the requested information.

Assess Energy Use

To assess your energy use you will need to gather information about:

- Energy Generation
- Offtakers
- Energy Consumption
- Peak Power Usage

Details about how to do these assessments can be found in the relevant section of the *Assessment Processes*. Continue with the flowchart once you've collected the requested information.

Consider Environmental Impact

Even though it is recommended to maximize the power output of the micro hydropower facility per foot of bypass reach (to guarantee minimal environmental impact on the stream ecology and habitat), specific local benefits generated by the micro hydropower facility might outweigh the local environmental concerns.

It is therefore essential to consult with regional environmental resource agencies and local stakeholders associated with the dam site and its stream. Installing micro hydropower in a way that serves the needs of the region will require technical assessments of the proposed hydropower facility, consideration of the possible benefits for the local community, and a full consideration of potential environmental impact at and near the site. For more information about environmental impacts[26] and stakeholder consultation[27], check out the microhydrony.org-website[28].

Consider Off-Grid System

An alternative to a grid-connected system is to design the hydropower system to match the on-site load, and directly wire the system to the buildings using the power and energy – with no connection to the distribution utility. This is referred to as an "off-grid" configuration. Here, the buildings using the power and energy need to be located in close proximity to the hydropower generation site. This is because the further away the generation source is from the site of consumption, the higher the cost is to directly wire the system to the load. One example of a configuration where an off-grid hydropower system may work is an old mill or factory building that may be redeveloped for a new purpose and that is already located close to their dams. The benefits of an off-grid system can include:

- No interconnection costs (studies, wires, meters)
- No utility meter readings
- Independence from grid-failures / power outages
- 100% renewable energy
- Energy autonomy
- Potentially reduced permitting requirements (and cost) if non-federal oversight[29]

The disadvantages of an off-grid system can include:

- Dependence on local equipment / No grid as back-up
- Need for on-site back-up power
- Oversized system to meet power demands / Increased system cost
- Grid is not balancing use patterns
- Additional wiring necessary

While off-grid systems promise greater autonomy and independence from the local utility grid, they most likely come at a higher cost to provide the same standard of electricity availability. Customers who are willing to compromise and adjust their habits and use patterns to the available electricity, could save significantly by going off-grid. It is also possible to connect to the new micro hydropower system by wiring directly and not interconnecting it to the utility, while also still keeping a utility account for back-up power to the buildings that are wired to the system. This can work whether the building already had an electric meter in place before the owner decides to develop a micro hydropower system and directly wire it, or if the owner decides to apply for new service at the building. If it is the latter, and the utility has not previously served that building, there will be additional costs to establish service which will vary depending on how close the building is to the distribution wiring system, and the anticipated back-up demand of the building(s).

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[26] https://microhydrony.org/get-started/environment/
[27] https://microhydrony.org/get-started/legal/
[28] https://microhydrony.org/
[29] To find out if your project falls under federal jurisdiction of the Federal Energy Regulatory Commission, file a Declaration of Intent. The FERC provides a simple template and more information on their website: https://www.ferc.gov/industries/hydropower/gen-info/comp-admin/jur-deter.asp. Alternatively, for more information on microhydro permitting, see https://microhydrony.org/category/legal/

If you decide to go off-grid, and use all of the generated electricity on site, the strength and distance to the electric utility grid are irrelevant. What is relevant is the distance to the energy users. A combination of multiple energy sources or at least the combination with a backup battery system can transform a micro hydropower project of the right size into an off-grid solution for your property.

For the off-grid option, assess

- Energy Consumption [kWh]
- Peak Power Usage [kW]

Assessing your peak power use is important for system design. Your micro hydropower system (in combination with your battery system) need to be able to provide enough power for your appliances to run simultaneously and thus match your instantaneous usage. The easiest way to assess your peak power usage is by assessing all appliances, all lights, all fans and all other electrical devices in your home.

Note: upgrading old appliances and lighting to more efficient units might allow you to install an overall smaller micro hydropower and battery system, ultimately being less expensive. See: *Consider Financial Impact*.

Consider Simple On-grid System

On-grid systems are grid-connected systems that depending on energy usage export or import energy from the electric utility grid. In contrast to an off-grid system, which uses a battery as backup, the grid will provide all necessary backup power if consumption exceeds generation at any moment.

The basic on-grid option is a micro hydropower system that is supplementing your local energy consumption with on-site renewable generation.[30]

Consider Hybrid-System

A hybrid-systems consists of multiple generation resources like hydropower, solar, wind, anaerobic congestion, battery storage. If your planned micro hydropower generation does not suffice to fully supply your on-site property consider adding solar or wind to increase the energy output. To stabilize the solar output you will need backup: battery (for an off-grid solution) or grid.

Consider Remote Net-Metering

A potential New York micro hydropower project may involve a situation where the desired location for the generation source is not close enough to feasibly physically connect to the meter where the owner wishes to use the energy output. In this instance, the project may be a good candidate for remote net-metering (RNM). RNM allows a project built on one site to allocate the energy output to receiving accounts in the same service territory, where all the accounts involved (host and receiving accounts) are owned by the same customer.

RNM is based on net metering, which allows electricity customers who generate some or all of their own electricity to send excess energy to the grid and receive energy from the grid when their load exceeds their on-site system generation. Net metering is really a billing construct required by law in New York

[30] Systems that use remote net-metering or Community Distributed Generation schemes need to be on-grid (grid-connected) as the utility organizes the transport of the electricity from the source to the consumer.

State, which obligates the electric utility to value the generation you make on-site according to net metering rules. RMN is an enhancement of traditional net metering, with the only major difference being that the energy system is off-site instead of on-site. Energy generated off-site is applied to the load at the customer's utility meter where they consume power, so long as both the generator and consumer meters are owned by the same customer and are within the same utility territory.

Under New York's RNM rules, the account to which the renewable energy system is connected is called the Host Account and must be a commercial or a farm account, which means that residential customers cannot take advantage of remote net metering as the host turbine site.[31] A micro hydropower site can be developed by setting up a new commercial account as the host, with the receiving account holder applying for the commercial host meter in their name. (For situations where a generation source is interested in sharing their output with different customers in the same service territory see Consider Community Distributed Generation)

Assess whether you own other properties, whose meters are in your name and which get electricity from the same utility company and how the total energy consumption compares to your planned Energy Generation [kWh].

Consider Community Distributed Generation

This model works best if your hydropower potential exceeds your own on-site electricity needs and the project can easily be interconnected to the local distribution utility. Under the Community Distributed Generation (CDG) program, the host has to directly market to and find retail customers, and bears the risk of managing a subscription business with monthly billing. CDG is not a long-term contract with a single offtaker; instead, it is an arrangement where the generation output of a project is allocated to a group of subscribers who may come in and out of the program during its lifetime. In the CDG model, the risk of not having enough subscribers to allocate generation output is born by the CDG host and mitigated by effective marketing and continuous solicitation of new subscribers.

New York's CDG program is a framework that exists within New York Public Service Commission regulation, however much of the specific design of a potential CDG is up to the CDG host. Key requirements of the CDG program include:

1. The CDG host may be any single non-residential entity that owns or operates electric generating equipment eligible for net metering pursuant to the utility Tariff. The CDG host is subject to Public Service Law Article 1 to the same extent as electric service companies (ESCOs) and other similar energy supply providers interacting with the utility.
2. A CDG host and all subscribers must be located within the same utility service territory and NYISO zone overlay.
3. A CDG host must serve a minimum of ten CDG subscribers.[32] Each CDG subscriber must receive a minimum allocation of 1,000 kWh annually. This means that a CDG host needs to have a minimum of 10,000 kWh anticipated average annual generation to qualify to set up a CDG.
4. No more than 40% of the generation output may serve CDG subscribers with 25 kW demand or greater, or put another way, 60% of the generation must serve mass market non-demand customers under 25 kW. No subscriber may receive more credit that it consumes in a year.

[31] See https://www.nyserda.ny.gov/Researchers-and-Policymakers/Power-Generation/Net-Metering-Interconnection

[32] There are exceptions for farms and coops who may set up CDG with less than ten subscribers.

5. The CDG host must execute the required contracts as set forth in the Standardized Interconnection Requirements (SIR)[33] Addendum in their corresponding utility tariff and must operate in compliance with the standards and requirements set forth therein. The SIR are established by the NYPSC, and each utility provides their SIR Addendum in their tariffs.
6. The CDG host must certify to the utility that it meets the creditworthiness standards established by the NYPSC and must agree that it will set processes and procedures in place related to cyber security and other requirements.
7. The CDG host must comply with oversight rules which are in development in Case 15-M-0180. For example, CDG hosts are required, by June 1, 2018, to (a) file a registration form with the Department of Public Service and (b) provide all mass market customers with completed disclosure forms at or before contract signing.
8. The CDG must submit the CDG Allocation Request Form at least sixty (60) calendar days before commencing the CDG program. This form must include each CDG subscriber's utility account number, name, address, and the percentage of the CDG host's net energy output to be allocated to each subscriber. The host must also certify that it has entered into written agreements with each of the CDG subscribers.

As part of this assessment step, please confirm the following:

- Do you expect the annual output of your facility (minus on-site consumption) to exceed 10,000 kilowatt-hours (kWh)? A CDG requires a minimum number of ten subscribers with a minimum allocation of 1,000 kWh per year each.
- Are you comfortable engaging your community to educate them about micro hydropower and to market your CDG, or would you consider hiring a subscription management organization?
- Are you interested in operating the CDG business yourself, or would you consider hiring a developer to build and operate your CDG?

If the answer to all of these questions is yes, consider operating your micro hydropower project as a Community Distributed Generation project. You can find more information about the Community Distributed Generation Program on microhydrony.org under Finance.[34]

Consider Power Purchase Agreement

If your hydro-site is physically adjacent to an entity that could use all of your electricity generation, you might be able to sell your electricity directly to this one entity using a Power Purchase Agreement (PPA). Alternatively, if you own property with micro hydropower potential, you might find a developer to build and operate the facility and to sell you the electricity output for your property. In either way, the owner of the generation source and the owner of the load are not the same entity, which defines the PPA. This model may:

- be an off-grid project, which means that an interconnection agreement with the distribution utility is not necessary;

[33] The NYPSC's Standard Interconnection Requirements (SIR) as of October 2018, on http://www.dps.ny.gov/, Case 15-E-0557.
[34] https://microhydrony.org/wp-content/uploads/2019/05/Microhydro-Financial-Models-Community-Distributed-Generation.pdf and https://microhydrony.org/get-started/finance/

- be able to use remote net metering if you own property with microhydro potential and load in a separate location, but you wish for someone else to construct, own and operate the hydro project and to sell you the output.

What you will need to assess is whether there is a potential offtaker near your project site that would use about as much or less energy than your expected Energy Generation [kWh]. If that potential offtaker is yourself, you will need to assess whether you are interested in an external developer building and operating your micro hydropower project and delivering you with the generated energy. In both scenarios a PPA could be the way to go. You can find detailed information about the Power Purchase Agreement on microhydrony.org under Finance.[35]

Choose Low-Head Turbine

Figure 12 shows the major turbine technology types available on the market. Low-Head Turbines include the Archimedes Screw and the Gravitational Vortex.

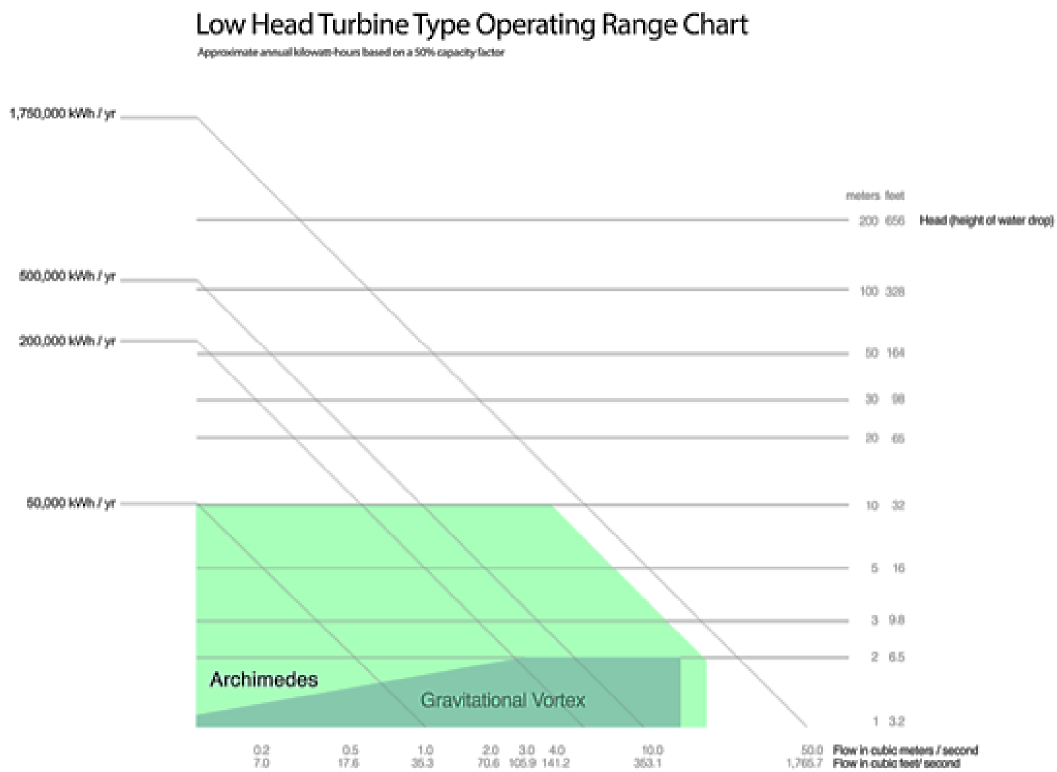


Figure 12 – Micro Hydropower Low-Head Turbine Technologies

The Archimedes Screw Turbine uses the principle of the Archimedean screw to convert the potential energy of water into a rotational moment that can be used by a generator, comparable to a water wheel (see Figure 13 for an example). The turbine's rotor is in the shape of an Archimedean screw that rotates in a semicircular trough. The weight of the water flowing into the turbine on the upstream end presses down onto the blades of the turbine forcing it to turn. Gearbox and generate at the upstream end of the

[35] https://microhydrony.org/wp-content/uploads/2019/05/Microhydro-Financial-Models-Power-Purchase-Agreements.pdf and https://microhydrony.org/get-started/finance/

turbine allow for electricity generation. Variations of the screw turbine focus on safe fish passage using a double-screw mechanism. Versions of this technology have been installed in different parts of the world, including the US and Europe.

Figure 13 - Two 75kW Archimedes screw turbines, Monmouth, Wales[36]

The Gravitational Vortex technology is a low-impact hydropower technology utilizing a stable water vortex to spin a simple turbine. Units consist of cylindrical rotation tanks with an orifice in the center of the bottom of the tanks acting as the outlet; the inlet is a penstock or water channel directing the water into a rotational movement (see Figure 14 for an example). This rotational movement in combination with gravity creates a water vortex which is utilized to spin a turbine in the center - thus the name Gravitational Vortex. The turbine shaft connects to a gearbox and/or generator above it.

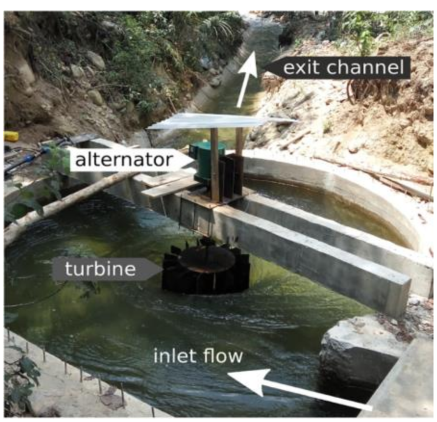


Figure 14 - Gravitational Vortex System with descriptions, Peru[37]

[36] Source: http://newsimg.bbc.co.uk/media/images/47431000/jpg/_47431298_fishpass.jpg

[37] Alzamora Guzmán, Glasscock and Whitehouse, 2019, Design and construction of an off-grid gravitational vortex hydropower plant: A case study in rural Peru, in Sustainable Energy Technologies and Assessments, Volume 35, October 2019, Pages 131-138: https://www.sciencedirect.com/science/article/abs/pii/S221313881830626X

GV-technology has been used successfully in Austria and other European countries, Asia, Australia and South America for the past decade, but has not yet been deployed in the United States in a run-of-river hydroelectric facility.

Choose Medium-Head Turbine

Figure 15 shows the major turbine technology types available on the market. Medium-Head Turbines include the Amjet, Crossflow, Francis and Kaplan turbines

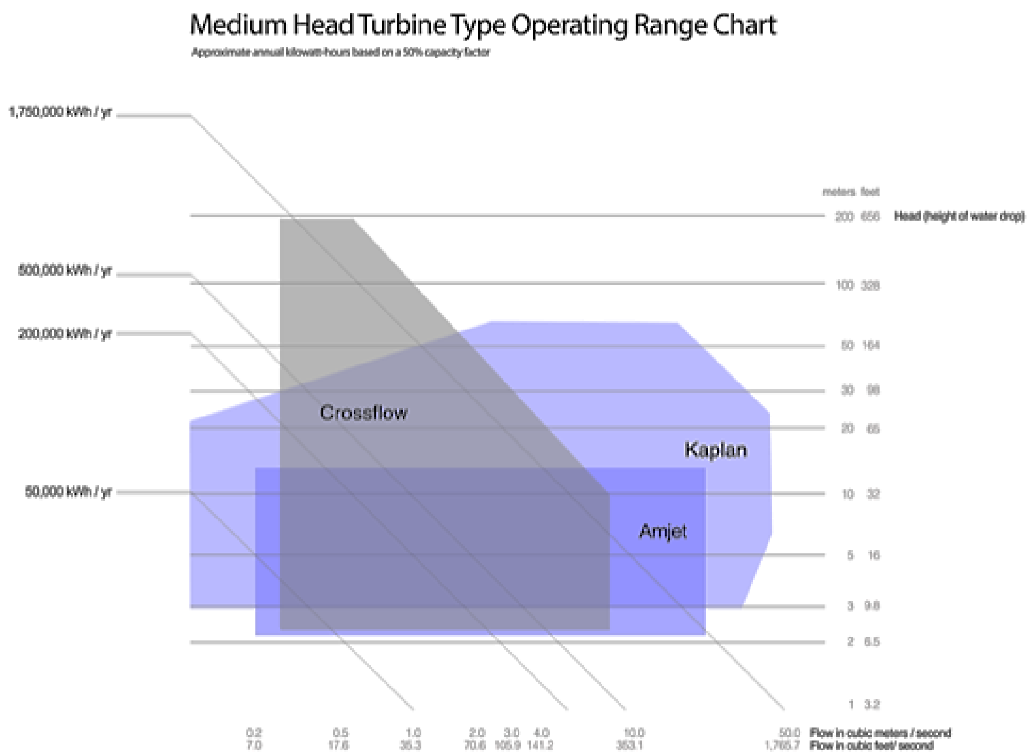


Figure 15 – Micro Hydropower Medium-Head Turbine Technologies

The Amjet turbine-generator-system is a US based small hydro technology that allows easy installation at medium heads and low flows (see Figure 16 for an example).

Figure 16 - ATS-63 all-composite turbine/generator installed in Mississippi dam, Brainerd, MN[38]

[38] Source: http://www.amjethydro.com/products.html

The Amjet system currently comes in three sizes: 8-inch, 32-inch and 64-inch diameter to adjust for different flow settings. This technology depends on a reliable electrical system that optimizes efficiency over varying flow settings. The only installation of this technology is at the Brainerd MN dam on the Mississippi.

Crossflow turbines have water pass through them transversely / across the turbine blades rather than axially or radially (see Figure 17 for an example). After passing through the inside of the runner, it leaves on the opposite side - effectively passing the runner blades twice and providing additional efficiency. Crossflow turbines are low-speed machines, well suited for locations with a low head but high flow.

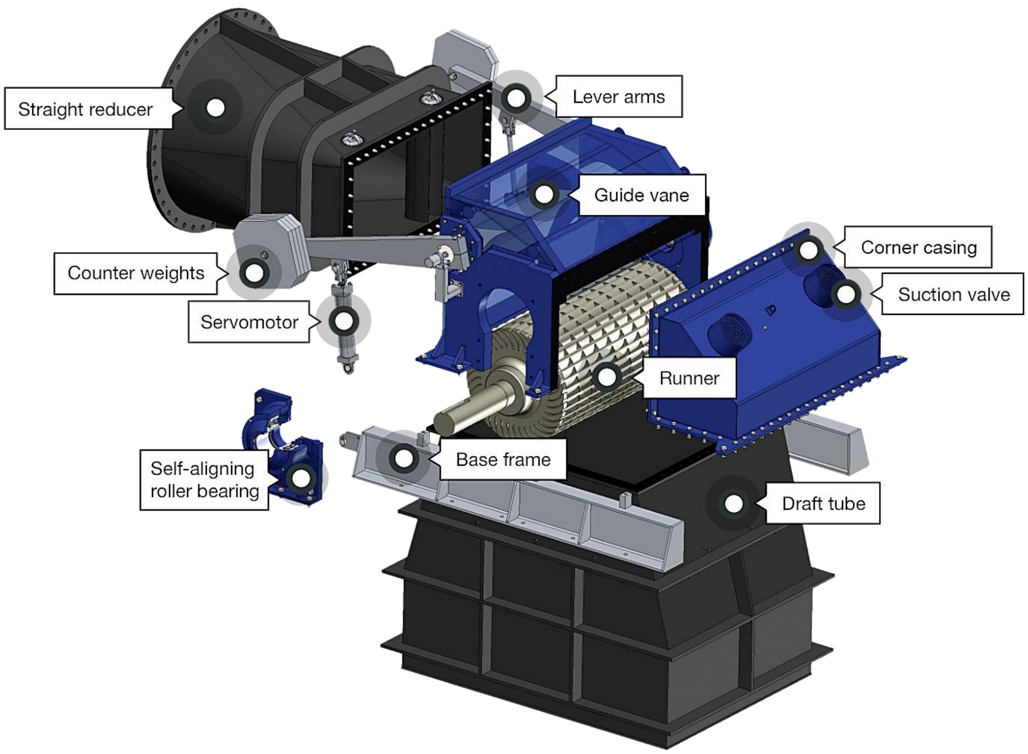


Figure 17 - Ossberger Crossflow Turbine Design with description[39]

This technology has been used since the early 1900s and has been installed all over the world. Many manufacturers offer crossflow units in different sizes and specifications.

Francis turbines are likely the most common water turbines in use today. They mostly operate in high head conditions, but smaller units can also be used in the medium head range. The turbine was developed by James B. Francis in Lowell, Massachusetts in 1848.

The Francis turbine has a spiral casing around the runner (volute casing or scroll case), guide and stay vanes to direct the flow at design angles to the runner blades and specifically designed runner blades at the heart of the turbine (see Figure 18). In contrast to the Pelton turbine (see *Choose High-Head*

[39] Source: https://ossberger.de/uploads/pics/explosionszeichnung_EN.png

Turbine), the Francis turbine operates best when completely filled with water, allowing the outlet channel to be placed lower than the downstream water level, reducing the tendency for cavitation.

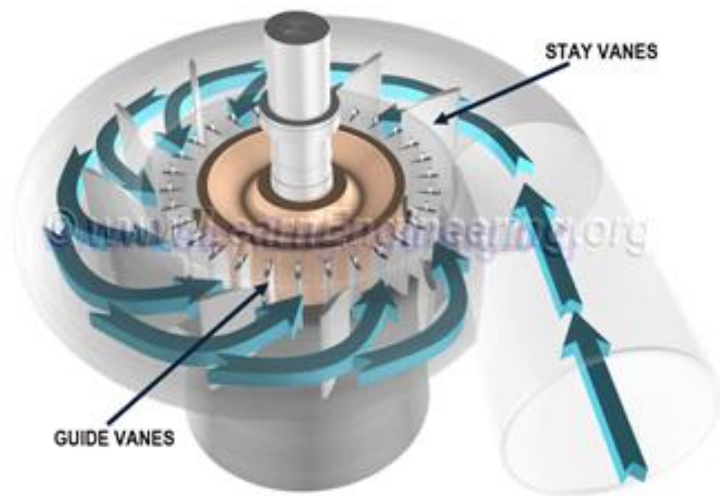


Figure 18 - Francis Turbine Schematic[40]

The Kaplan turbine is a propeller-type water turbine with adjustable blades (see Figure 19). Viktor Kaplan developed the turbine in 1913 when he combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow parameters. The Kaplan turbine was an evolution of the Francis turbine, allowing more efficient power production in medium-head applications. Similarly, Kaplan turbines have been installed all over the world.

Figure 19 - Kaplan Turbine Rotor[41]

[40] Source: https://www.learnengineering.org/how-does-francis-turbine-work.html
[41] Source: http://www.cmr-hydro.it/images/img-prodotti-turbine-kaplan1.jpg

Choose High-Head Turbine

Figure 20 shows the major turbine technology types available on the market. High-Head Turbines include the Francis, Pelton and Turgo turbines. See *Choose Medium-Head Turbine* for a description of the Francis turbine.

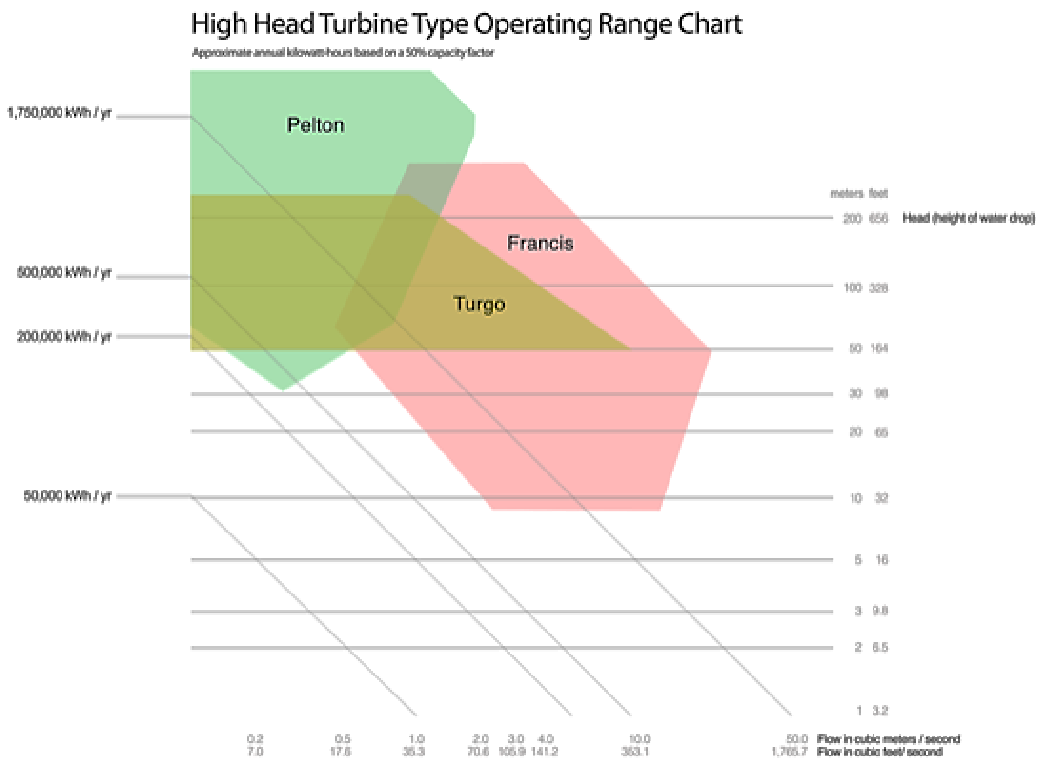


Figure 20 – Micro Hydropower High-Head Turbine Technologies

The Pelton turbine (see Figure 21), more often referred to as the Pelton wheel, is an impulse-type water turbine invented in the 1870s.

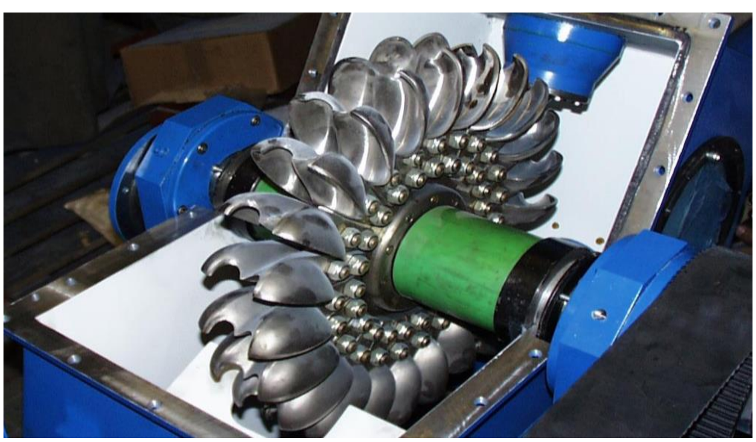


Figure 21 - Pelton Wheel[42]

[42] Source: https://cdn6.bigcommerce.com/s-hqdwu/product_images/uploaded_images/pelton-2.jpg?t=1427403379

The technology extracts energy from the impulse of moving water instead of the potential energy like traditional overshot water wheels. Nozzles direct forceful, high-speed streams of water against the impulse blades (spoon-shaped buckets), located along the outer rim of the runner. And although Pelton wheels are made in all sizes, they are preferred for high-head / low flow settings.

The Turgo turbine (Figure 22), designed in 1919 as a modification of the Pelton wheel, has a runner that is half the diameter of comparable Pelton wheel runner, and thus offers twice the specific speed. The Turgo turbine can also handle a greater water flow than a Pelton of comparable size. With a little imagination one can see that the Turgo looks like a Pelton wheel cut in half.

Figure 22 - Turgo Turbine[43]

Manufacturers of high-head turbines often offer and sell all three technologies: Francis, Pelton and Turgo - sometimes even Kaplan turbines as well.

Assess Environmental Suitability

Besides the technical feasibility and parameters, environmental aspects of the project need to be considered. This is necessary to ensure the proposed project isn't doing more harm than good, and also a requirement during the permitting process.

You will be required to assess the existing conditions, planned changes, expected impacts and proposed measures to counter these impacts for:

[43] Source: https://hydroturbine.blogspot.com/2016/04/turgo-turbine.html

- River Basin, Streamflow and Water Regime
- Terrestrial Wildlife
- Rare, Threatened and Endangered Species
- Recreation and Aesthetics
- Socioeconomics
- Historic and Archeological Resources
- Land and Water Use
- Geology, Soils and Groundwater
- Surface Water Quality
- Sediment Quality
- Fish, Benthos, and Aquatic Plants
- Wetlands
- Terrestrial Vegetation

With regard to the existing conditions, most of this information can be obtained from online maps provided by environmental resource agencies, local and state agencies and non-profit organizations. Other things might need the expertise of ecologists and engineers. Planned changes, expected impacts and proposed countermeasures are directly related to the facility design. Talk to your developer for a proper site assessment and a detailed design.

Start your micro hydropower Journey!

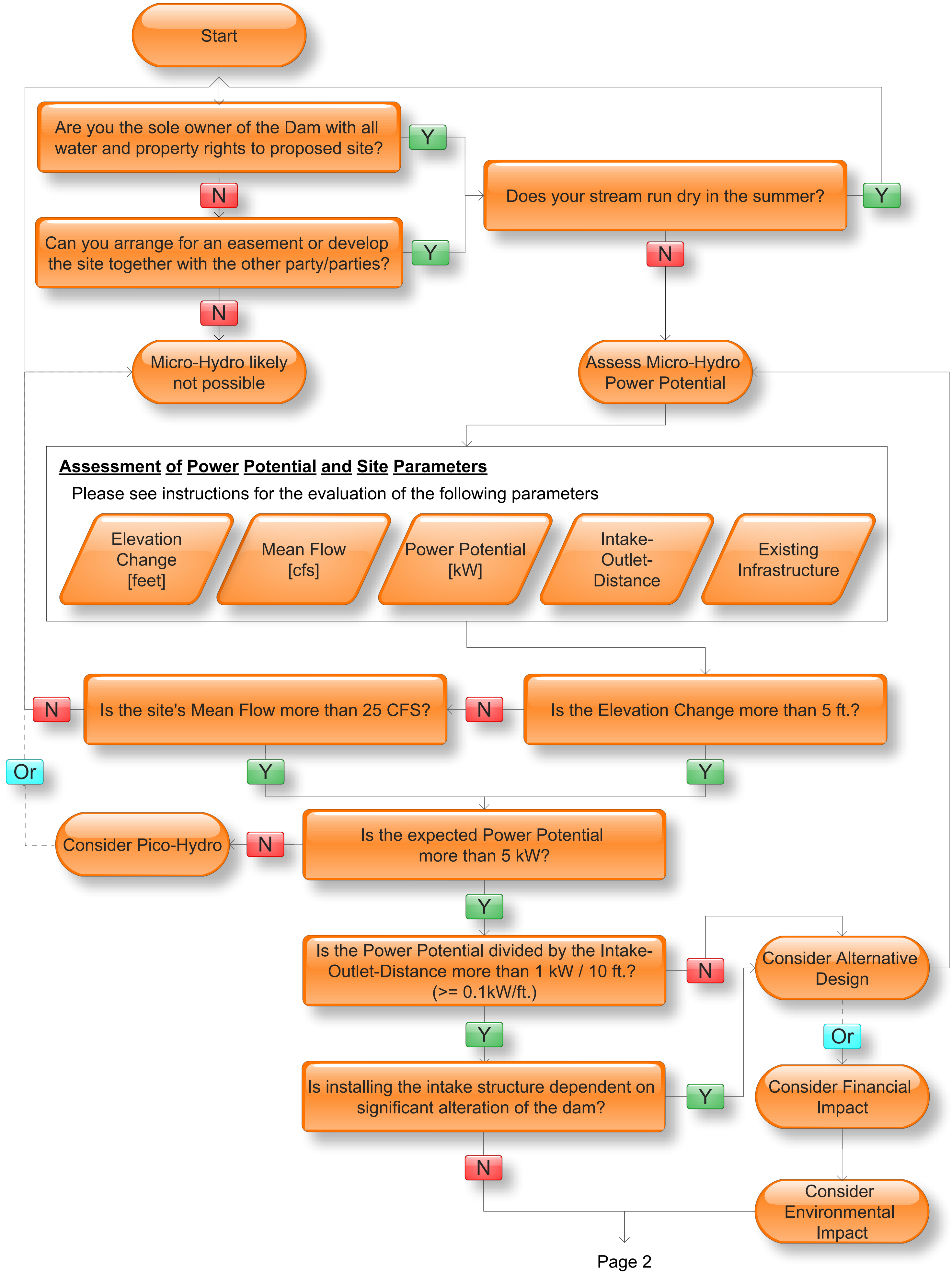
For more information about how to start you own micro hydropower project, visit https://microhydrony.org/

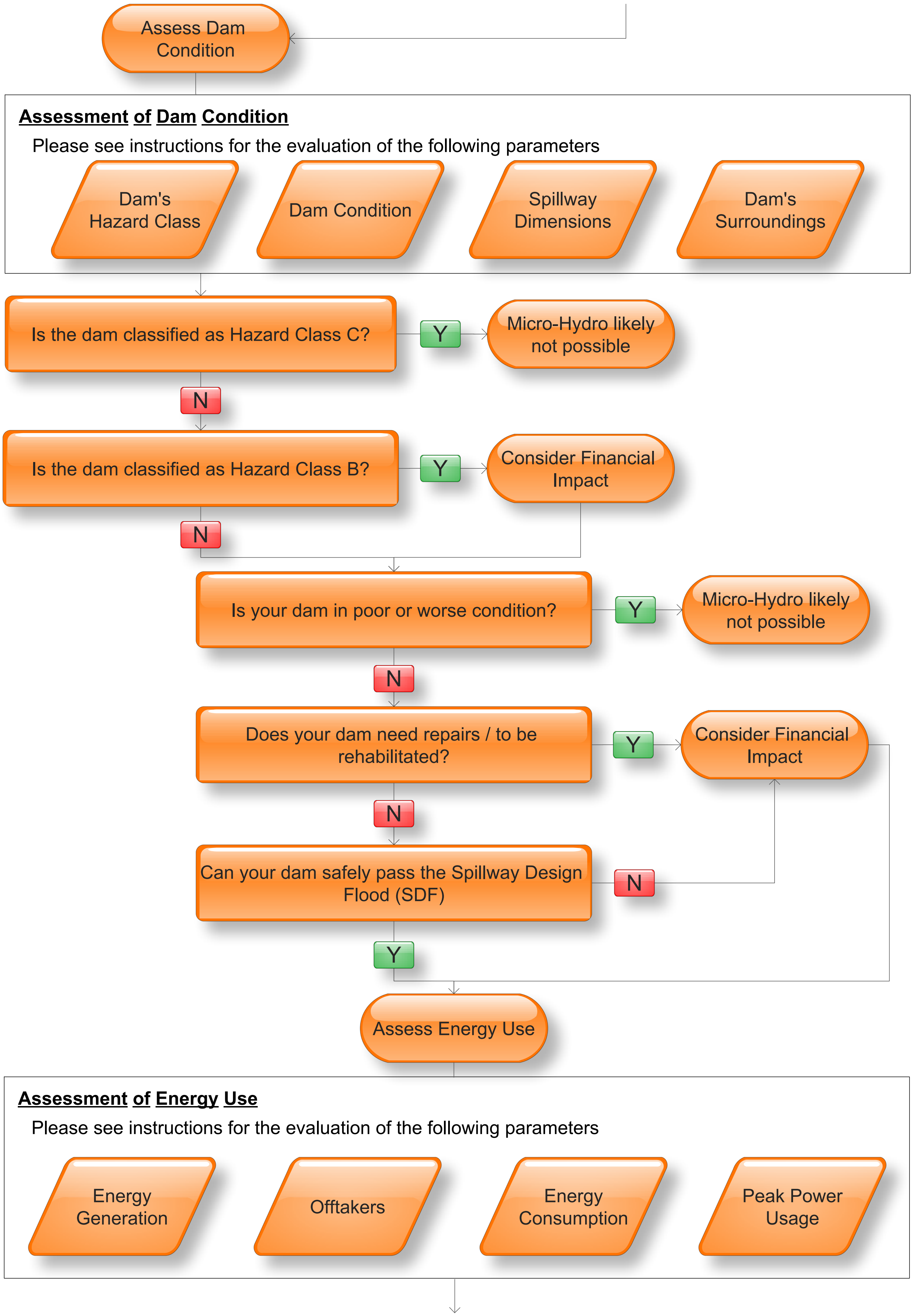
Summary

This flowchart is designed to assist stream-side property owners in making technological decisions about the potential installation of a micro hydropower project. Site specific parameters influence if and what kind of micro hydropower technology can be feasible and will need to be assessed prior to coming to a technical decision. The flowchart guides the site-owner through the decision-making and assessment process and offers simple explanations and recommendations for a multitude of settings.

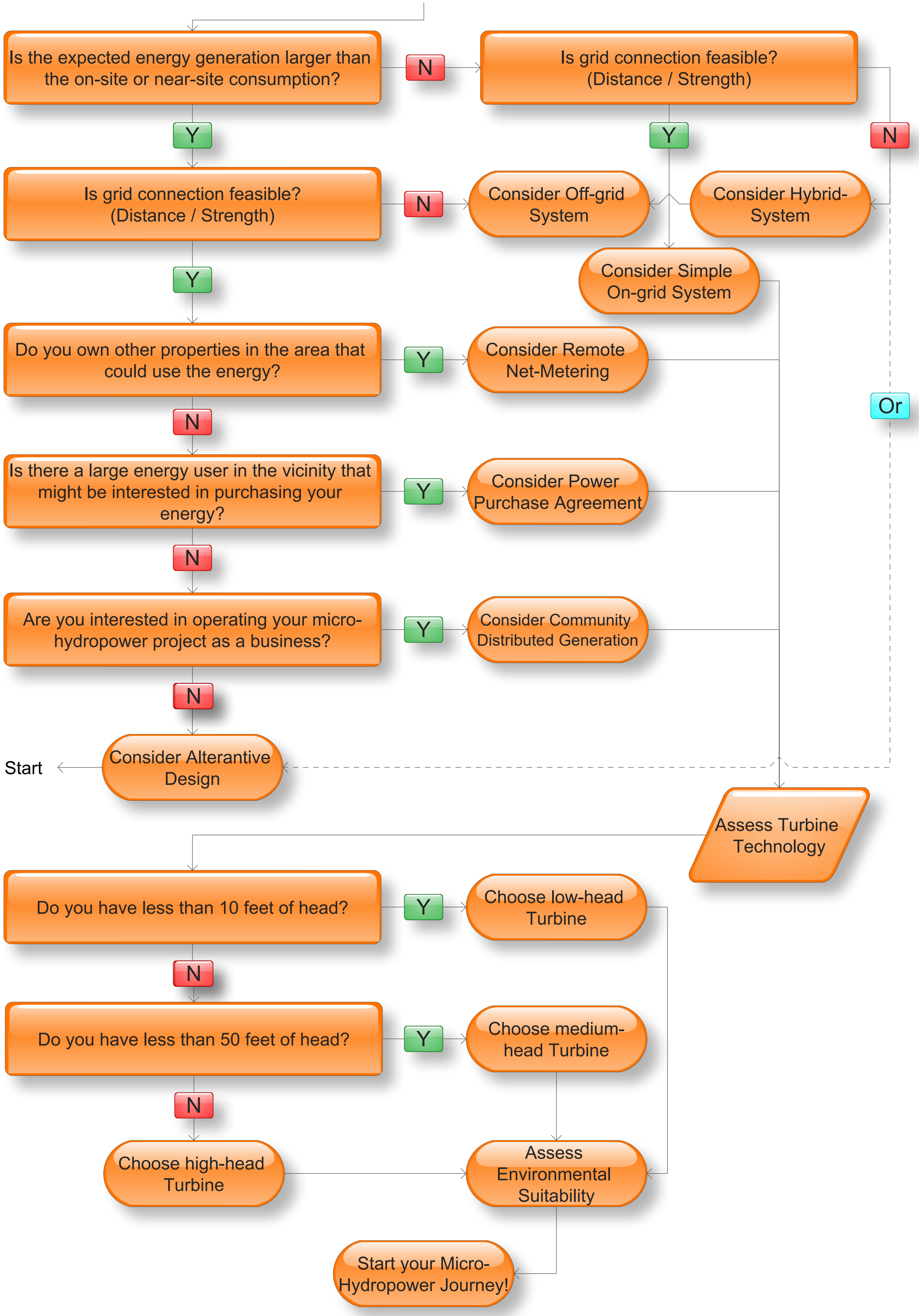
One aspect of micro hydropower development has only been touched and not discussed in detail as part of this decision-making framework: environmental considerations. It is strongly recommended to visit the microhydrony.org-website and to learn about necessary environmental considerations when planning a micro hydropower system.

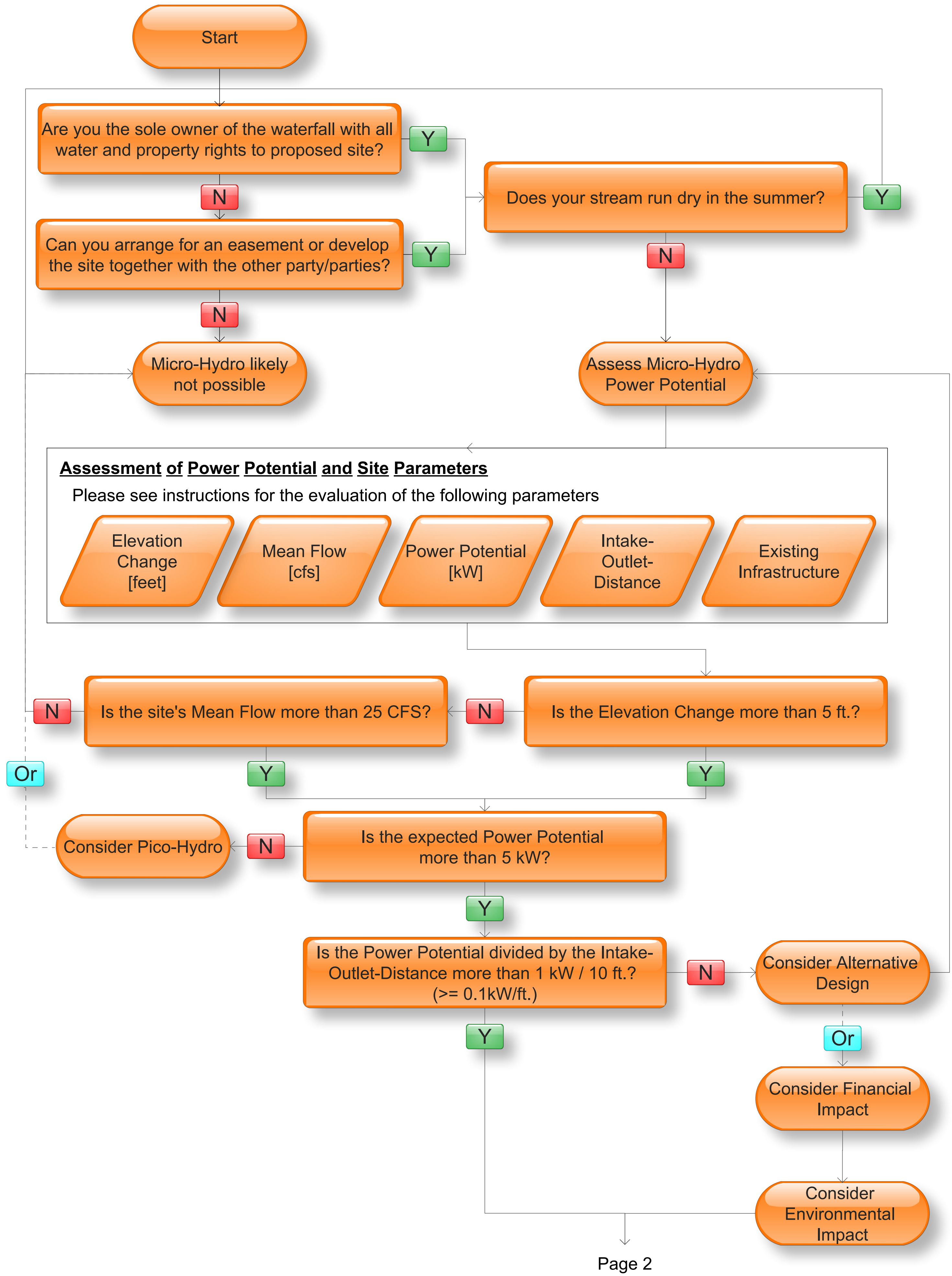
Appendix: Decision-Making Framework Flowcharts

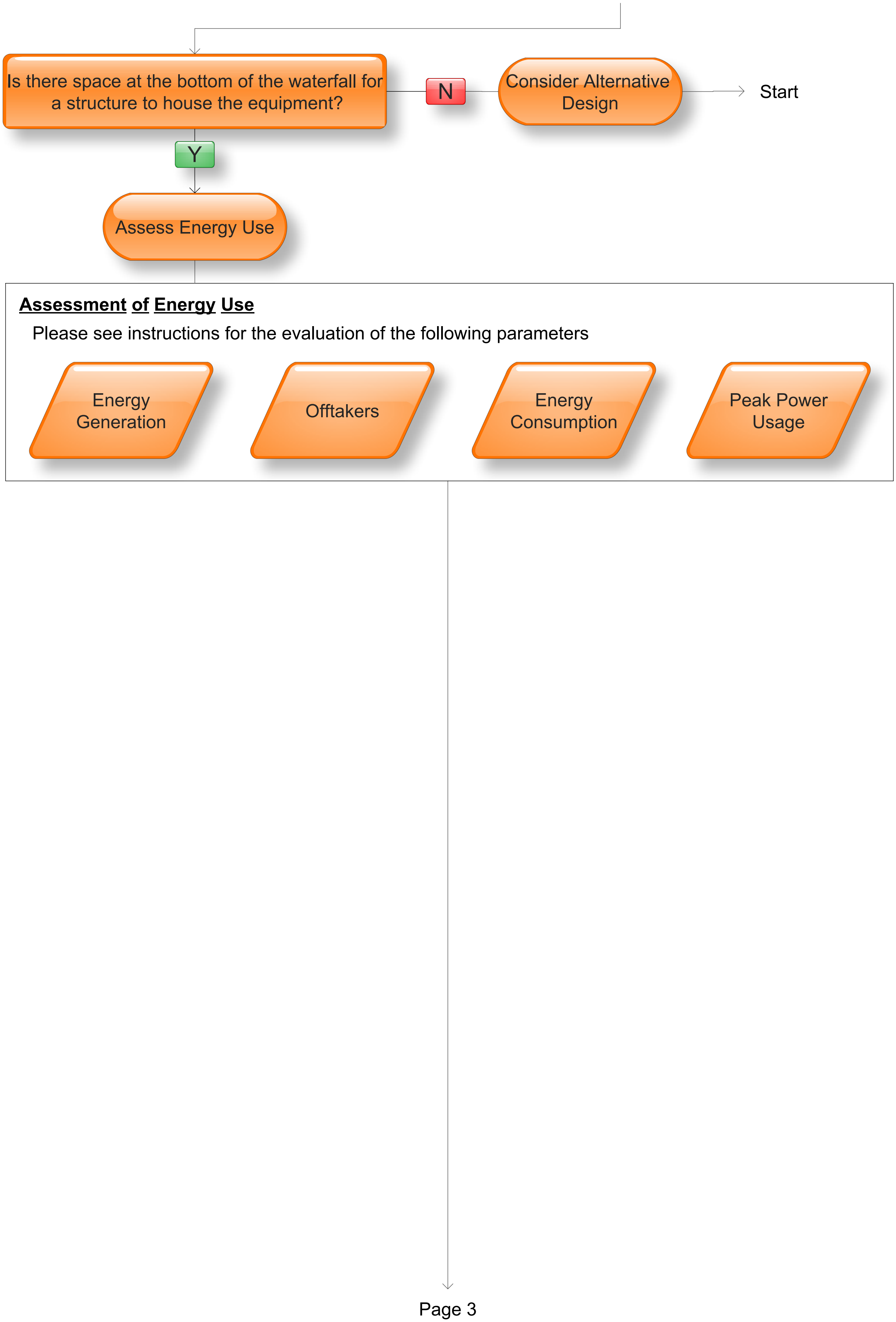

Start
Are you the sole owner of the Dam with all water and property rights to proposed site?
Y
N
Can you arrange for an easement or develop the site together with the other party/parties?
Y
N
Micro-Hydro likely not possible
Does your stream run dry in the summer?
Y
N
Assess Micro-Hydro Power Potential
Assessment of Power Potential and Site Parameters
Please see instructions for the evaluation of the following parameters
Elevation Change [feet]
Mean Flow [cfs]
Power Potential [kW]
Intake-Outlet-Distance
Existing Infrastructure
Is the site's Mean Flow more than 25 CFS?
N
Is the Elevation Change more than 5 ft.?
N
Or
Y
Y
Consider Pico-Hydro
N
Is the expected Power Potential more than 5 kW?
Y
Is the Power Potential divided by the Intake-Outlet-Distance more than 1 kW / 10 ft.? (>= 0.1kW/ft.)
N
Consider Alternative Design
Or
Y
Is installing the intake structure dependent on significant alteration of the dam?
Y
Consider Financial Impact
N
Consider Environmental Impact
Page 2


Assess Dam Condition
Assessment of Dam Condition
Please see instructions for the evaluation of the following parameters
Dam's Hazard Class
Dam Condition
Spillway Dimensions
Dam's Surroundings
Is the dam classified as Hazard Class C?
Y
Micro-Hydro likely not possible
N
Is the dam classified as Hazard Class B?
Y
Consider Financial Impact
N
Is your dam in poor or worse condition?
Y
Micro-Hydro likely not possible
N
Does your dam need repairs / to be rehabilitated?
Y
Consider Financial Impact
N
Can your dam safely pass the Spillway Design Flood (SDF)
N
Y
Assess Energy Use
Assessment of Energy Use
Please see instructions for the evaluation of the following parameters
Energy Generation
Offtakers
Energy Consumption
Peak Power Usage

Page 3


Is the expected energy generation larger than the on-site or near-site consumption?
N
Is grid connection feasible? (Distance / Strength)
Y
Y
N
Is grid connection feasible? (Distance / Strength)
N
Consider Off-grid System
Consider Hybrid-System
Y
Consider Simple On-grid System
Do you own other properties in the area that could use the energy?
Y
Consider Remote Net-Metering
Or
N
Is there a large energy user in the vicinity that might be interested in purchasing your energy?
Y
Consider Power Purchase Agreement
N
Are you interested in operating your micro-hydropower project as a business?
Y
Consider Community Distributed Generation
N
Start
Consider Alterantive Design
Assess Turbine Technology
Do you have less than 10 feet of head?
Y
Choose low-head Turbine
N
Do you have less than 50 feet of head?
Y
Choose medium-head Turbine
N
Choose high-head Turbine
Assess Environmental Suitability
Start your Micro-Hydropower Journey!


Start
Are you the sole owner of the waterfall with all water and property rights to proposed site?
Y
N
Can you arrange for an easement or develop the site together with the other party/parties?
Y
N
Micro-Hydro likely not possible
Does your stream run dry in the summer?
Y
N
Assess Micro-Hydro Power Potential
Assessment of Power Potential and Site Parameters
Please see instructions for the evaluation of the following parameters
Elevation Change [feet]
Mean Flow [cfs]
Power Potential [kW]
Intake-Outlet-Distance
Existing Infrastructure
Is the Elevation Change more than 5 ft.?
N
Is the site's Mean Flow more than 25 CFS?
N
Or
Y
Y
Is the expected Power Potential more than 5 kW?
N
Consider Pico-Hydro
Y
Is the Power Potential divided by the Intake-Outlet-Distance more than 1 kW / 10 ft.? (>= 0.1kW/ft.)
N
Consider Alternative Design
Or
Consider Financial Impact
Consider Environmental Impact
Y
Page 2


Is there space at the bottom of the waterfall for a structure to house the equipment?
N
Consider Alternative Design
Start
Y
Assess Energy Use
Assessment of Energy Use
Please see instructions for the evaluation of the following parameters
Energy Generation
Offtakers
Energy Consumption
Peak Power Usage
Page 3


Is the expected energy generation larger than the on-site or near-site consumption?
N
Is grid connection feasible? (Distance / Strength)
Y
N
Y
Is grid connection feasible? (Distance / Strength)
N
Consider Off-grid System
Consider Hybrid-System
Y
Consider Simple On-grid System
Do you own other properties in the area that could use the energy?
Y
Consider Remote Net-Metering
Or
N
Is there a large energy user in the vicinity that might be interested in purchasing your energy?
Y
Consider Power Purchase Agreement
N
Are you interested in operating your micro-hydropower project as a business?
Y
Consider Community Distributed Generation
N
Start
Consider Alterantive Design
Assess Turbine Technology
Do you have less than 10 feet of head?
Y
Choose low-head Turbine
N
Do you have less than 50 feet of head?
Y
Choose medium-head Turbine
N
Choose high-head Turbine
Assess Environmental Suitability
Start your Micro-Hydropower Journey!