	Requirement	Recomm-endation
C1. General	1 **Durability.** All civil works must be durable and maintainable to 15 years, except in cases of specific components where rebuild is explicitly included and costed in the management plan. 2. **Optimisation.** Civil works must be designed for adequate and safe performance at minimum expense. 3. **Flow closure**. Reliable methods of diverting flow from the silt basin, canal, forebay, and from the penstock, so that these components can be quickly emptied whenever required, must be included in the design, and must be **tamper-proof.** There must be at least two flow diversion devices if there is a canal included in the design. 4. **Maintenance and materials**. The use of high quality materials and construction techniques will result in less maintenance and repair work through the life of the scheme, whereas low-cost construction will require considerable maintenance. Both approaches are acceptable, though the first approach is recommended for most schemes of larger capacity. The **management plan** must make provision for high maintenance activity and cost in cases of low-cost civil works. 5. In all schemes **concrete** is recommended for the turbine base and for penstock anchor blocks; it can be used in medium-cost headworks, canals, and forebays to provide strength and erosion resistance in vulnerable areas such as the floor of the canal and forebay/silt basins, and the intake mouth. *When visiting verify the above and in addition:* 6. Check for **leaks** from all civil constructions. These can quickly give rise to expensive damage and must be fully repaired before the scheme is put to use. Also repair cracks or any faulty work which could give rise to problems at a later date. 7. A reliable and rapid **shut-down** or emptying method must be **demonstrated** for the silt basin, canal, forebay, and penstock. Close all gates, then progressively open each one to check that overflows work safely.	
C2. Weir and intake	1. Natural weirs. Particular attention must be paid to the **choice of site** for the intake. The river bed must not be in danger of deepening (due to scouring action) or in danger of changing course, such that an intake built to function with a natural weir would cease to function. 2. During **low river flow** conditions (such as the 5-year drought), the intake must continue to draw water in accordance with consumer expectations for power supply. In schemes where seasonal drying out of the intake is a possibility, the management of the scheme must be **planned** to allow for this, and **contracts** with consumers and tariff agreements must allow for periods of **power shut-down.**	

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	3. The intake must be of a passive design; that is, it must function in **5-year flood** conditions without any need for operators to make adjustments or work close to flooded area. 4. If the weir and intake are a **temporary structure**, designed to be swept away high flow conditions, the **seasonal replacement** of this structure should be **costed** into the management plan, and provision made in consumer agreements for power shut down during the rebuild period. 5. Intakes must be designed to operate **reliably without clogging** with sediment and debris. If a very low-cost design is adopted which is prone to clogging, provision must be made in the management plan to replace and upgrade as necessary. (An example is the use of a submerged pipe as an intake, which occasionally can work in some conditions, but will more often present problems and need to be replaced with a more reliable design). *When visiting verify the above and in addition:* 6. Check that the intake is not in danger of **clogging**. If it is, upgrade the design. 7. If a natural weir used, check for signs of bed **scouring** and changes of course. If **gabions** are used to define the river course, check that a natural bank is developing around them to provide stability as the gabion mesh disintegrates over time.	
C3. Schemes without open canals	1. If the penstock starts at the intake, the headworks should follow **spillway and forebay tank** design principles with respect to deflection of flood waters and prevention of **stones/debris** entering penstock and air entrainment. Desilting may be necessary as detailed. The penstock entry section must be secure against flood water and boulders/trees etc carried by flood water. The requirement for a reliable method of **penstock closure and emptying**, which can be activated during flood conditions, is particularly important. 2. **Air-traps**. If a **closed canal** or headrace is used, such as a pipe, it is required that: a. either the pipe is laid without high points or low points b. or if there are high points (or potential high points resulting from settling), then these must be protected from air traps either by vent pipes rising to above static head level or by air release valves c. if there are low points these should be fitted with flush valves to allow removal of debris blocking the water flow d. water will start to flow through by itself when it is diverted toward the system, without any need for priming	
C4. Headrace, spillway, desilting basin	1. The **site** chosen for headworks must be **stable** and suitable for installation of reliable foundations. The presence of trees on the bank can indicate stability. 2. Headworks must be built to a high standard to **avoid cracking** and leaks. Ensure that stones are laid across potential leak paths rather than along them, that mixtures are correct, that filling is carefully done, and inside corners are finished well. 3. **Spillway.** All excess water must return to the river safely and	

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	automatically in the case of flood flows. 4. All **debris** taken from the river must either return to the river automatically before entering a canal or penstock, and or be deposited in such a way that removal is an easy maintenance task and no blockage of flow occurs. 5. If the turbine manufacturer recommends silt removal then installment of a silt basin is required. A **silt basin** must be designed to optimise performance with minimum of expense, by ensuring that **turbulence** is not induced at any point. It must be designed so that **flushing** or emptying is an easy maintenance task.	
C5. Open canal and environment	1. **Water speed.** The flow of water in the canal must not be so fast that the canal walls are eroded or that excessive head is lost, and not so slow that silt settlement will clog the canal. *Water velocity design guidelines are:* *Minimum (silty water) 0.3 m/s* *Maximum (Sandy soil) 0.4 m/s* *Maximum (Medium soil) 0.6 m/s* *Maximum (Clay soil) 0.6 m/s* *Maximum (Clay) 0.8 m/s* *Maximum (Masonry) 1.7 m/s* *Maximum (Concrete) 1.7 m/s* 2. The canal must be able to accommodate **rain storms** resulting in ingress of excessive slope run-off, by use of transverse **crossings, and spillways**, **and culverts.** These items must be designed so that they do not block easily (over-reliance on small culverts is best avoided because they are prone to blockage). 3. Locate the canal carefully as for headworks. The **slopes** above and below the canal must be **stable** or **rapidly** stabilised, especially if the digging may have caused disturbance, for instance by planting of grasses, to avoid the danger of heavy rains and slope erosion damaging the hydro system. 4. On larger schemes, and whenever possible, it is recommended to install a **footpath** along the length of the canal.	
C6. Forebay tank	1. The water level in the forebay must be sufficiently high above penstock mouth to avoid danger of **air entrainment**. A guideline is that the depth of the top lip of the penstock mouth below the water surface should exceed $1.5v^2/20$ where v is the penstock velocity in m/s. 2. The forebay tank must have a **spillway system** which is capable of reliably diverting maximum possible excess water (ie turbine flow if penstock or turbine shut plus additional flow due to rain storm) away from forebay, penstock, and power house foundations. 3. The forebay must have a **trash rack** with the following features: -easy to rake clean, ie parallel bars without cross-bars, and matched to rake size, provision of standing space for rake-holder - locked in place so that it cannot be moved by unauthorised people -gaps small enough to protect turbine from debris but not so small that rapid blockage creates a maintenance problem 4. Design variations and additions which serve these purposes are	

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	permitted as long as they are cost-effective. For instance low-cost alternatives to trash racks are permissible but must be replaced if ineffective. (An example is the use of a penstock pipe with holes drilled into an endcap - attention should be paid to the additional head loss induced and replacement with a trashrack if periodic declogging is not effective). 5. A **locked forebay cover** is recommended, and essential if mischievous behaviour is considered likely. 6. The penstock mouth must be **above floor level** so that nearby small stones and silt deposits are not entrained or pushed in. *When visiting verify the above and in addition:* 7. Check that **air** is not being **entrained** into the penstock mouth. 8. Test forebay **spill system** by shutting off turbine and ascertain that it can accommodate excess conditions without danger to foundations. 9. The forebay tank must be in a **good state** of maintenance without leaks, cracks, signs of progressive deterioration.	
C7. Vent pipe	1. Penstocks must be protected from vacuum damage by a vent pipe immediately **downstream** of the penstock mouth and downstream of any valve located in the penstock. 2. **Safe design**. The vent pipe mouth must be designed and installed in such a way that it is highly unlikely to become blocked, or have mud or stones inserted. For example, a U-turn entrance can help accomplish this, a locked box cover which has multiple vents, or endcapping and drilling of small holes in the sides of the vertical pipe.	
C8. Penstock pipework	1. Since penstocks are usually one of the most expensive components, they must be carefully selected and sized to operate at an **optimised efficiency** which balances head loss against cost. In addition, they must be able to safely withstand surge pressures as well as static pressure. A check should be carried out as detailed in the attached notes. The choice of **safety factor** will depend on site conditions A safety factor of four times the combined surge and static pressure is recommended, although a reduced factor can be used in small schemes (less than 10 kW) and where all the following conditions apply: -the cost of penstock replacement is not excessive -the spill resulting from a failure does not pose danger to the power house, the local community or farm land, etc -the penstock is installed by an experienced team and tested in excess of the total pressure on site -the turbine and valve design is such that surge pressure conditions are highly unlikely to occur The manufacturer's safety factor should be **quoted** or a **efficiency and burst calculation** presented as shown in the attached notes. 2. **Joints** must be of type recommended by the manufacturer to fulfill pressure ratings 3. **Seam-welded** pipes, must be pressure tested before use (sample testing may be sufficient) and covered by manufacturer's warranty against weld defects	

	4. **Penstock flow velocities** must not exceed 3 m/s. *When visiting verify the above and in addition:* 5. The entire penstock should be checked for **leaks**, particularly around joints and flanges. These must be immediately corrected as they can lead quickly to expensive damage. 6. During commissioning, the penstock must be **pressure-tested** to more than the sum of surge and static head.	
C9. Protection of steel penstocks	1. Above-ground steel penstocks should be **clear of the ground** to avoid corrosion and to allow easy access for paint. 2. Steel pipes must be given **two coats of paint** on the outside and the maintenance plan must include regular repainting. Internal painting is recommended. Standard metal oxide paint can be used, although the recommended paints are: *Outside: Zinc chromate primer followed by polyurethane enamel top coat.* *Inside: Bitumen (easier to apply, use rag or brush); or lead oxide (more difficult to apply).* 3. If **steel** penstocks are **buried**, they must be coated with bitumen. It is preferred that they are galvanised, and double-coated with either bitumen or high zinc content paint. 4. **Tar paper or bitumen** must be used between steel pipework and supports/anchors to exclude water and air which may collect in inaccessible areas and promote corrosion. **Rubbing plates or tar paper** are recommended between pipework and support piers to prevent abrasion due to thermal expansion and contraction. Rubbing plates should not be used if they pose danger of air and water entrapment which may lead to corrosion. Tar paper or bitumen may be needed on either side of a rubbing plate to avoid this. 5. **Expansion joints** are recommended on steel penstocks: • one immediately below forebay tank or integrated into forebay tank wall • between each anchor block one below final anchor block on sites of more than 10 kW with a high head and complex manifold which may be vulnerable to stress. *When visiting verify the above and in addition:* 6. Overground steel penstocks should be inspected to ensure that there are no areas where rain water can accumulate and cause **corrosion**. Check that this is being done as part of a routine maintenance schedule, and that corrective action is routinely taken (ie clearing of plant growth touching the penstock); and that repainting is undertaken periodically. 7. Overground penstocks should be checked to ensure that thermal expansion will not cause **wear** at any sliding support. 8. During commissioning check that **expansion joints** are **not closed** up tight to one end of their movement as this may cause leaks and failure. Check that operators know how to reset expansion joints after works are carried out on the penstock.	

C10. Protection of PVC and HDPE penstocks	1. PVC and HDPE pipes often give good service without special protection from either sunlight or thermal expansion and contraction forces. Nevertheless it the following precautions can improve the cost-effectiveness of the scheme: a. **PVC** penstocks can be protected from **sunlight** by paint or some other sort of effective and durable covering; or by burying. b. **Expansion/contraction.** PVC pipes with spigot and socket joints can accommodate thermal forces without special measures. If a glued PVC pipe is not buried and is straight, a socket and spigot joint is recommended between anchors and at the forebay to accommodate thermal forces; alternatively some inclusion of flexibility in the run of pipe. 2. If **PVC** penstocks are **buried** they must be laid on sand beds without danger of stress points occurring below or above the pipe surface due to objects such as stones butting against the walls of the pipe.	
C11. Penstock supports and anchors	1. Anchors and supports must be **sized** and designed to reliably accommodate all possible sliding, toppling, and sinking/lifting forces. 2. Supports should be designed to allow some longitudinal **sliding** between the penstock and the support. Supports must be fitted with a **vertical** movement **retention** method, to accommodate lifting forces. 3. **Anchors** should be constructed from concrete, preferably reinforced. Special attention should be given to ensuring that their **foundations** are sound and not likely to move (as this will cause severe difficulties in handling the turbine manifold, and jeopardise the forebay and penstock).	
C12. Powerhouse floor	1. **Size**. The floor area must be sufficiently large to allow the turbine and generator to be accessed from all sides and dismantled, and to allow heavy equipment to be moved around. Machinery must be positioned to allow access from all sides. 2. The floor must be **sloped** so that all water drains toward the tailrace of the turbine. 3. The floor surface should be **above ground** level to prevent flooding in heavy rain.	
C13. Powerhouse door	1. The door must **open outwards** for safety reasons. 2. **Size**. The door must be sufficiently large to allow passage of heavy machinery. 3. The door should be **lockable**.	
C14. Powerhouse windows	1. The **window area** should be 1 m^2 for every 10 m^2 of floor area, in order to ensure adequate ventilation and light. 2. The windows should not be glazed but have instead **wire meshes** or grills to allow ventilation. These should be strong enough to ensure security. 3. An underground powerhouse will require equivalent provision for light and ventilation.	

C15. Powerhouse security	1. **Security.** The powerhouse as a whole should be secure and lockable to prevent unauthorised entries and to protect children from possible accidents.	
C16. Powerhouse roof	1. **Ceiling height** should not be less than 2.5m at lowest point. 2. The roof should have a **gap** where it meets the wall to allow warm air to escape 3.Roofing materials must be made of the **lowest fire-risk** material possible, such as clay tile or corrugated iron. 4. The roof should be extended to prevent **rain** entering the window grills. 5. The roof should be reliably **watertight**.	
C17. Powerhouse ventilation	1. **Ventilation**. As noted in the specifications for the roof and windows, the powerhouse must be designed to ensure good ventilation at all times especially when the doors and window grills are locked and the machinery is unmanned. Ventilation must be **passive** and reliable not dependent on machinery such as fans.	
C18. Tailrace	1. The tailrace must be sealed and **leak-proofed** with cement for a minimum distance of 3 metres from the power house. After this masonry can be used to direct water away from the power house. Leak-proof evacuation is essential to protect the powerhouse foundations. 2. Sloping tailraces must be built with **steps** or rock protuberances to break the waterspeed and give protection from erosion.	
C19. Powerhouse flow-meter	1. To monitor scheme performance it is useful to build into the tailrace channel a **flow measurement weir**. In circumstances where the flow allowed for power generation is limited this facility is particularly useful. It is also useful in circumstances where a clear indication of turbine and generator efficiency is required. An alternative is to use the salt-dilution flow measurement method between forebay and tailrace, but a weir will allow much quicker and easier readings of flow.	
C20. Powerhouse industries and agro-processing	1. Mechanically or electrically driven appliances such as grain-mills or oil expellers should be operated in a **separate room** of the powerhouse wherever feasible, or mesh dividers used to separate the powerhouse machinery from applications.	

Summary of recommendations. **Approve civil works on condition that:**	**Recommendations fulfilled:**
Proposal stage: *Date recommendations filed............* *Recommendations by........................*	 *Approval date.........* *Approval by...........*
Construction stage: *Date recommendations filed............* *Recommendations by........................*	 *Approval date.........* *Approval by...........*
Commissioning stage: *Date recommendations filed............* *Recommendations by........................*	 *Approval date.........* *Approval by...........*
Warranty completion stage: *Date recommendations filed............* *Recommendations by........................*	 *Approval date.........* *Approval by...........*

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Note C8. Penstock selection

The calculation procedures given here can be used to check that the selected penstock is an optimum choice. They can also be used during initial design of a scheme to choose a penstock from scratch. Take the following steps:

1. If working from scratch, consult a pipe manufacturer’s catalogue of products and use the velocity equation below to find a diameter which gives a velocity of about 2.5 m/s.

2. Alternatively enter the details of the penstock proposed in the scheme design you are checking, meanwhile also verifying its availability and refer to the manufacturer’s information.

3. Enter also the material (PVC, HDPE, or steel are the most common materials for penstocks) and the wall thickness of the proposed pipe.

4. Use the calculation procedures below to find the net head and efficiency of the pipe. A penstock efficiency of around 95% is typical for microhydro sites. If the efficiency is very high the penstock will be large and too expensive. If the efficiency is low the penstock will be cheaper, but it is likely that the losses will be excessive and the power output will be too low. The formulae assume conservative values of the roughness coefficient, k. For steel pipes, this assumes that the joints have weld protruding into the bore, and that a rough paint finish is used. For HDPE, it is assumed that the joints are heat-formed welds with internal beads impeding the flow. The k value for PVC assumes bonded joints but with some internal gaps between the pipes. The calculations ignore minor head losses from the inlet, bends and valves.

5. Select alternative diameters to find pipes which give satisfactory net head figures. Try this for different materials which are available.

6. To establish the required penstock wall thickness, it is necessary to identify an appropriate safety factor. In most instances a factor of four is recommended, though this can be reduced for small schemes and in the special circumstances described in the specifications. Enter the chosen value onto the selection table.

7. Enter also the wall thickness of the selected pipe. To calculate the required wall thickness, it needs to be ascertained whether the fastest likely closing of the manifold valve will take more time or less time than the critical time. The critical is the time required for a pressure wave to travel the length of the penstock and back, and is a function of the wall thickness.

8. Use the calculation procedure to find the required wall thickness. If you are in doubt as to the valve closure time, choose a time which is less than the penstock critical time, and use the equation for surge head taking closure time as less than critical time; this applies to situations such as instantaneous blockage of flow by for instance a stone jamming the nozzle of a pelton turbine. This is the safer and more common approach to the design of the penstock.

9. If the flow change is caused by a slow valve closure, and there is no chance of the penstock (or a branch of the manifold) being blocked instantaneously, then the closure time may be greater than the critical time, and the second equation applies. This might be the case for crossflow turbine with a control valve that can only be closed slowly, or a Pelton turbine with

a gate valve that is protected from fast closure by gearing or by the use of a smaller valve fitted in parallel.

10. The factor ‘z’ is the % of the flow that changes velocity. So, for a four jet Pelton turbine, if one nozzle blocks, z will be 25%. The value of z should be put into the equations as a percent (not as a fraction).

11. A corrosion allowance is added for steel penstocks. An allowance of 1·0-1·5 mm is usual for a lifetime of 10-15 years, but this can be increased if a longer life is required, or reduced if a good protective coating is used inside and outside the penstock.

12. Enter the calculated required thickness onto the selection table. The proposed penstock thickness must be equal to or greater than the calculated required thickness. It will usually be necessary to use the next standard thickness of material up from the required thickness. If the required thickness comes out less than the trial thickness, increase it and try again.

13. For PVC and HDPE it is possible to compare the total head calculated with the rated head from the manufacturer. This avoids the need to calculate thickness and is preferable if the manfacturer’s ratings are credible.

Note: Excel spreadsheet files containing the calculations below are available. The files are:
pensteel.xls
penhdpe.xls
penpvc.xls

Table C8. Penstock selection table.
Selected wall thickness must equal or exceed calculated required thickness

Site name:	Penstock length:			Flow:		Gross head:		
Reference (Manufacturer)								
Description								
Material								
Nominal diameter								
Proposed wall thickness								
Calculation results								
Net head								
Efficiency								
Required safety factor								
Total head at surge								
Manufacturer’s rating for HDPE or PVC pipe								
Calculated required thickness								
Cost of penstock								
Note on optimisation of cost and performance								

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