DESIGNING HYDRO SCHEMES FOR REMOTE AREAS

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1 INTRODUCTION

Small hydro schemes can be divided into two broad categories: those that operate in parallel with a large power system and those that supply all or most of the power needed by a small isolated system. In the former case, the designer should aim to maximise the amount of energy that can be generated from the available water. Efficiency is important and governing is not. In the second case, governing is important and efficiency is not a major factor.

This paper is about the problems and options facing a designer who has to design a small hydro scheme to supply a remote area far from a power grid. The main population centre has one or more small (less than 100 kW) diesel generators. Surrounding villages do not have any supply.

In the area there is a river or stream with hydro potential.

2 THE DESIGNER'S OPTIONS

The designer must first consider what he is trying to achieve and then evaluate the options.

Initially, he must establish how much power is needed and how this will increase with time as the load increases and new villages are supplied.

Then he has to work out how far it is economic to run distribution lines to supply these villages. If the electricity authority have a “standard” design for rural distribution which is based on an urban distribution system using heavy conductors, close pole spacing and large (50 -100 kVA) 3 phase transformers, then it may be marginally economic to supply, say, a village with a 50 kVA load 10 km distant.

If, on the other hand, the electricity authority have adopted a low cost distribution system using light conductors, small (10-30 kVA) transformers and single phase or Single Wire Earth Return (SWER) distribution, then supplying a 50 kVA load 20 km distant is likely to be economic.

In either case, the designer will need to decide which villages could be economically supplied by the hydro station.

The engineer must then estimate:

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(a) the initial load and subsequent load growth in the population centre and;

(b) from the rate of construction of rural distribution and rural load growth, the rural load increase over the next ten years or so.

From these two he can produce year by year estimates of peak demand and load growth.

The next step is to check if there is sufficient hydro potential to supply the peak demand:

(a) all the time;

(b) most of the time;

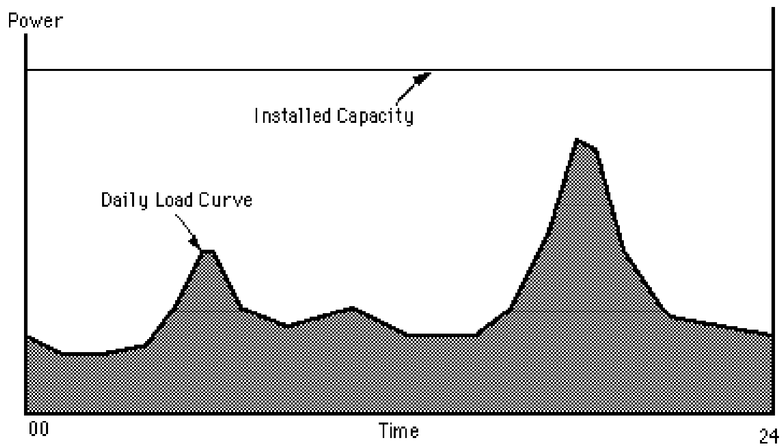
(c) some of the time;

(d) never.

If there is plenty of water and the peak demand can be supplied all the time, then operation, control and governing problems, are relatively simple. If (b) or (c) then the designers are likely to have a difficult and interesting task. If (d), the hydro station will have to operate in parallel with diesel or other generating plant. Under these circumstances the hydro plant should be designed for maximum energy production and operation, governing and control are not major considerations.

To illustrate the different approaches required, we will take two imaginary power schemes, both supplying similar loads. One, which we will call "Wai-nui" (Maori for "big river"), could develop much more power than the prospective load. The other, "Wai-iti" (little river), could generate enough power during the six month wet season but drops to about 30% power during the dry season.

The load is predominantly rural, but it includes a small town now supplied by diesels. The load curve looks something like this:



When the rural electrification programme is complete the peak demand will be 350 kW. In ten years time, it is estimated to increase to 750 kW.

3 THE WAI-NUI SCHEME

This is a high head scheme; the stream flows from an elevated basin down a steep slope which ends on the coastal plain. The station is sited at the bottom of the slope. The head is 450 m, the penstocks are 1600 m long and the minimum flow is 180 l/sec.

This flow will give an output of 800 kW or more for 95 % of the time.

The designer now has to choose:

- the type, number and rating of the machines;
- control and governing systems.

Reference to one of the excellent papers by Siervo & Leva[2] shows that only a Pelton turbine can be considered. The designer's first impulse is to choose two 400 kW sets, the second being installed a few years after the first. Then she calculates the main parameters of the turbines rated for 400 kW and 800 kW, and produces the following table:

Unit Output	400 kW	800 kW
Head	450 m	450 m
Unit Speed	1500 rpm	1500 rpm
Specific Speed/Jet	14.5	20.5
Max Specific Speed/Jet	21.5	21.5
Jet diameter	37 mm	53 mm
Runner Dia-mean	550 mm	550 mm
Runner Dia/Jet Dia	15	10.3
Runner Dia - Overall	700 mm	720 mm

After studying the results, she realises that the fact that the 800 and 400 kW sets have the same runner diameter is significant. The size of the runner is the major factor in the cost of a Pelton turbine, so the turbine cost will increase by only 5 % or so if she chooses a single 800 kW turbine rather than one of 400 kW. Overall the cost of the generating set will increase by 15% or so. (Although the output of the generator will double, its cost is small compared with the turbine.) This extra cost will be more than offset by the lower cost of a control system, switchgear and powerhouse all designed for the future installation of a second 400 kW generating set.

So our designer writes a report recommending one 800 kW machine and presents it to her boss who says, “One machine won't be reliable. You must have two, in case one breaks down”.

[2] “Pelton Turbines” F. de Siervo & A. Lugaresi, WP&DC Dec '78

She goes away despondent, thinks hard, does some research and returns. She says, "I agree that our power station must be reliable. But having two machines instead of one will cost a lot more and will give only a marginal improvement in reliability."

"Why?"

"Firstly, experience with our other stations shows that small turbines are very reliable. Unless we have problems with cavitation or erosion they are down for inspection for only one or two days a year. Secondly, our biggest reliability problem has always been the intake. During floods they often get blocked and it may be several days before they can be cleaned. Thirdly, the conduit and penstock cross unstable ground and if it slips it will take several weeks to repair the pipeline. The probability of this is much greater than the probability of a major failure of the machine. Therefore, putting in two machines will give only a small improvement in overall reliability."

The boss says, "So what *are* you going to do about an emergency supply if the station is shut down for any of these reasons?".

She replies "Put in a 750 kW diesel."

"In a *hydro* station?"

"Yes."

"You must be crazy!"

"That's what I thought, at first. But the more I looked at it, the more logical it got. An 800 kW Pelton plus the diesel costs much less than two 400 kW Peltons and in addition the diesel covers for any failure between the intake and the transformer. On top of that, with a diesel it will be easy to shut down the scheme for minor maintenance or inspection. From our other schemes, we know that minor maintenance like cleaning intakes, de-silting, repairing subsidence and inspection and adjustment of the machine is usually deferred because it means shutting down the power supply. With a diesel it will be easy to maintain supply, and so this the work will be done. And if we do get a major failure of the intake or penstock, or if there is a sudden load increase, the diesel will be invaluable."

After long discussions, her boss sees the logic in the arguments, and agrees.

Governing is the next problem. When re-starting after a shutdown on an isolated system, large blocks of load will be thrown on the machine. With a 1600 m penstock the flow cannot be changed rapidly so it will only pick up load in 10 - 20% steps. Therefore, restoring the system will be a tedious job because linemen will have to be sent out to sectionalize the system. To improve the situation, large diameter penstocks (to reduce the water starting time) and a large flywheel to increase the inertia of the set are often used. Both are expensive.

Our designer thinks hard about the problem and realises that, when picking up blocks of load, the output of the turbine must change rapidly. She wonders if it it possible to change the output of the turbine without changing the flow. After all, this scheme has plenty of water so there is no need to control the flow in order to conserve water. So why not use the jet deflector to regulate the turbine power and have a simple manually adjusted spear? She makes some more enquiries and finds that years ago, this was the accepted way of governing a small Pelton turbine. She also discovers that a 'knife' type jet deflector is needed. So she decides to specify deflector governing with a manually operated spear.

With this, operation and control are very simple. The machine is started by slowly opening the spear with a handwheel. Once the set is up to speed, the governor moves the jet deflector 'in' to maintain normal speed. When the jet is wide open, the set can pick up full load easily because the governor moves the deflector out of the jet in less than two seconds if a substantial load is thrown on the machine. (If the governor takes more than two seconds, then there is something wrong with the specification or the design of the governor.).

So there we have it; a low cost hydro station, with simple controls and with 100% reserve capacity. It runs continuously and governs perfectly. It could have had water level transmitters, a surge chamber, large diameter penstocks, and two sets each with automatic starting and stopping, flywheels, and complex governing systems controlling the spear as well as the jet deflector. Yet all this complication would have made the scheme more expensive to build and maintain and less reliable. Remember, "If you don't have it, it won't give trouble".

4 THE "WAI-ITI" SCHEME

This is a typical diversion scheme, taking water from a stream that carries gravel, silt and vegetation during floods. There is not enough water during the dry season, so a head pond was included in the initial design. The nearby town centre has an established diesel station with surplus capacity.

The gross head is 70 m and the mean flow is 1.5 m^3/sec. To generate 800 kW requires 1.4 m^3/s.

This designer is faced with an entirely different set of problems - but he is still trying to achieve the same thing - a reliable and economic supply of power.

For the intake, he wisely decides to use a stream bed intake with a de-silting chamber. After reading a few good papers[3] [4] he shapes his screen bars like this:

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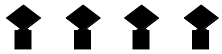
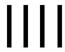
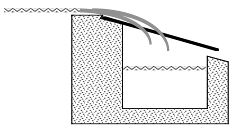
[3] "Experience de L'EDF Dans Le Domaine De Prix DeEau De Haute Montagne A Chasses Automatiques", Ponsard, Malbert, Chardonnet. *L'Houille Blanche* No 8 1967.

 instead of like this: 

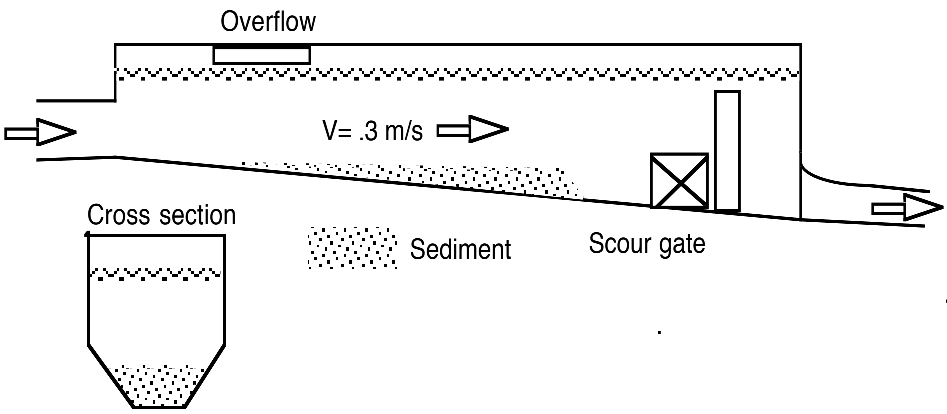
so that sticks and stones don't get wedged in between them. He also fixes them at the upstream end and leaves the downstream unsupported, like this:



so that leaves and debris don’t get caught on the downstream end of the bars. He provides for an adjustable orifice at the exit from the intake so that the diverted flow can be matched to the demand. (There is no point in diverting more water than you need because with it comes a lot more sediment.)

The de-silting basin is generously sized, and has a large scour gate that discharges above flood level, because the designer realised that being able to scour during a flood is very important. In addition, he left access holes in the settling basin so that the operators could check to see if it needed scouring. There is a submerged wall between the settling basin and the conduit intake so that the penstock can be isolated simply by operating the scour valve. This saves the cost of a conduit inlet valve and a vent.

The settling basin looks like this:



The low pressure conduit between the intake and headpond is 2000 m long. At full load flow, the head loss is four metres and so in the preliminary design, the headpond level was set 4 m below the intake level. The headpond has an emergency spillway. Our designer suddenly realises that most of the time, the machines will be taking much less than full load flow. The surplus flow cannot be allowed to go over the spillway because of erosion problems. What can be done? His first thought is to install an electrically operated valve at the

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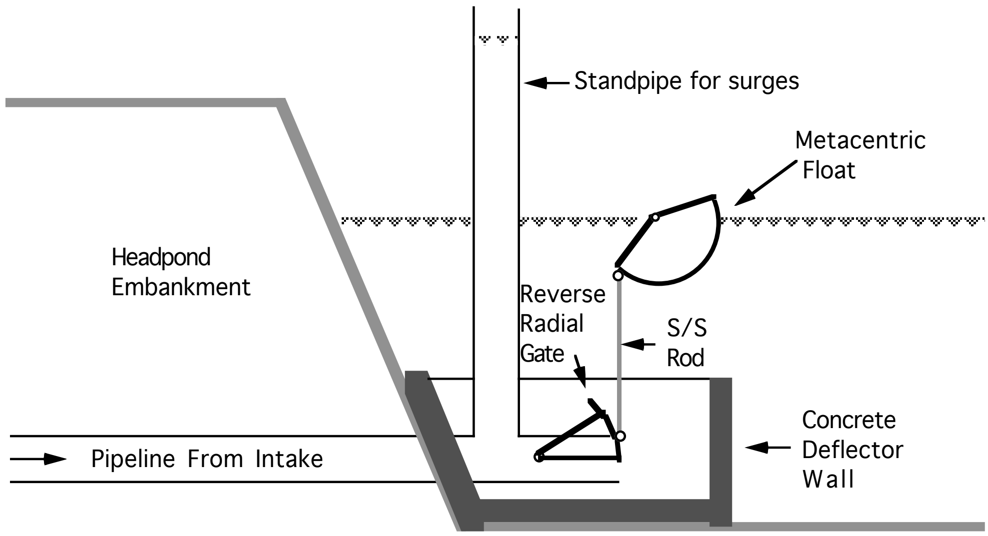
[4] “River Intakes For Small Hydro” D.R. Preston. *IAHR Conference, Melbourne 1985*

headpond which is controlled by a float switch. But he decides that it will be too complicated and the cost of a power supply to the intake is too high. He does a successful literature search into float controlled gates[5] and the final design looks like this:



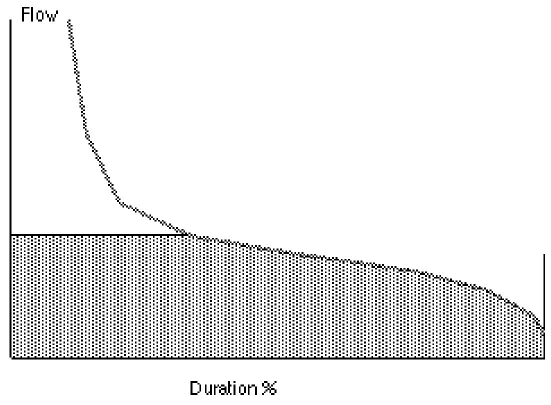
The metacentric float moves through a large angle in response to a small change in water level and so regulates the flow. The standpipe protects the pipeline against pressure surges.

Penstocks are the designers next problem. They will be about 400 m long and made of steel. Initially it was thought to be too expensive and more exotic materials such as glass reinforced plastic were considered. But the authority had just adopted "Value Engineering" and when this was applied to the cost of penstocks, sandblasting and painting with expensive epoxy paint emerged as one of the main cost factors. The engineers then investigated the life of ordinary painted steel in the locality and found that a life of at least forty years could be expected. As this was much greater than the guaranteed life of the more expensive GRP pipes, ordinary painted steel was adopted.

Then came some critical decisions: the determination of the installed capacity and the number and type and arrangement of machines.

A Francis turbine is the obvious choice - but should there be one or two?

[5] "Automatic Controls for Spillway Gates and Outlets" B.W.Leyland, G.R.Jessup, S.R.Berry. WP & DC January 1986



The flow duration curve shows that there will be sufficient water to run at full load for about 35 % of the time and the flow is below 40 % of full load flow for about 5 % of the time. However, because the night-time load is low, the station output will be less than 40 % of full load for a large part of the time.

Our designer has read that Francis turbines should not be operated at less than 40 % load, so he proposes a station with two turbines. But, mindful of what his colleague learned about the merits of simplicity with the Wai-nui scheme, he chooses twin turbines with a generator between them. When the flow is less than 50 % one turbine shuts down and the other operates near its best efficiency point.

He discusses this idea with a visiting turbine designer (who happens to be from Scandinavia and hence, very direct).

The turbine designer says "Where did you get this crazy notion that Francis turbines cannot operate below 40% load? It is just not true"

"Well...lots of people say so... and isn't it in the IEC Code for cavitation damage?"

"Firstly, these people are wrong: Francis turbines *can* be run at low loads, and secondly, the IEC code has misled a lot of people. Here are the facts:

- Francis turbines - especially large ones - tend to surge and operate unstably in the 40-60% load range due to the formation of vortices in the draft tube. As a general rule, the problem is more severe if the turbine is set well below tailwater level. Above *and below* this band, they are stable. Any small turbine should be stable over the whole operating range. If it is not, then admitting air to the centre of the runner will usually solve the problem"
- The IEC Code specifies a load range down to 40 % because large turbines seldom need to operate at lower loads. Cavitation tends to be a problem at high loads and is rarely severe at low loads. Anyway, small turbines should be specified to be cavitation free, so low load operation should not cause any cavitation problems with your turbine."

He goes on. "In reality, the only good reason for having more than one Francis turbine in a small station is increased efficiency. This is worth money only if low efficiency results in increased consumption of diesel fuel. Below 50 % load, the turbine efficiency drops rapidly so if the flow duration curve is very steep, and a single turbine would spend say 40 % of the time below 50% load, (which may well be the case if the region has a prolonged dry season) then having two turbines may result in a significant increase in annual generation. If the saving in diesel fuel justifies the extra cost and complication of two turbines, then by all means have them" So a single turbine is chosen.

Station operation is the next problem to be addressed. When the flow in the river is low, the station relies on headpond storage to provide sufficient power over peaks. As the load increases, the headpond storage will be insufficient, and the station will have to run in parallel with diesels. What must be done to ensure that the operators can run the system to make the very best use of the water and minimize running the diesels?

The designer goes along to his boss who says: "We have several stations with headponds that run in parallel with diesels over peaks. Why don't you go and talk to the people who operate them?"

So, he travels out into the Ulu and a meeting is convened. The first question is "How do you manage the storage in the headpond during peaks?"

"We don't. We start up a diesel every evening and run it at 70 kW. We have found that this allows us to get over the peak without any problems."

"But don't you keep an eye on the headpond level and start the diesel only if you are running out of water?"

"The headpond is 500 m up the hill. We can't dash up and down the hill all evening checking the level."

"Then why don't you fix your water level transmitter?"

"We haven't got one"

"But what is the use of a headpond if you don't know how much water there is in it?"

"That's what we would like to know."

After more discussions, the designer emerges a wiser man, with much sympathy for the operators and some admiration for the way they have managed to operate their scheme in spite of the lack of vital indications and communication links.

When he returns to his office, he produces the following operating policy:

The key to economic operation of a hydro diesel system is operating the hydro station so that water is never wasted and full use is made of headpond storage to minimize diesel generation over peak periods. To do this, the operators must know the headpond level and the output of the stations.

Operation will be as follows:

1 *During off-peak periods, while there is sufficient water available, the headpond will be full and the hydro station will supply all the load and control the system frequency.*

2 *During peak periods when there is sufficient water, a diesel will be started when the load on the hydro set approaches 700 kW. When the hydro set reaches full load, the frequency will drop and the diesel will pick up the extra load under the influence of its governor. As the load drops, the diesel will unload and shut down.*

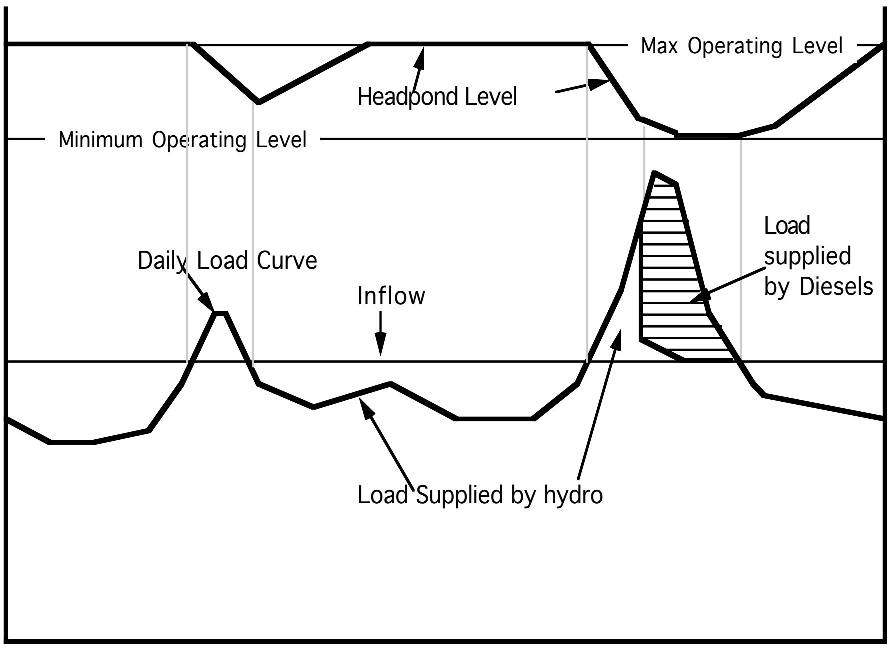
3 *During peak periods, when the river is low, the turbine will take more and more water as the load increases until it uses more than the inflow. At that point, the headpond level will commence to drop.*

4\. *When the headpond level drops to about half full, a diesel will be started and loaded to about 60% of rated load. (Because it is uneconomic to operate a diesel at light loads.) The hydro station will then pick up any subsequent load increase until the headpond level is close to its minimum operating level. From then on, the hydro set will be operated to maintain the headpond at its minimum level. The hydro operator will do this by adjusting his governor. If he has to reduce load, the frequency will fall and the diesel will pick up extra load. Similarly, if the headpond level increases, he will increase load and the frequency will rise and the diesel will reduce output.*

5 *As the demand drops after the peak, the diesel will carry less and less load until it is completely unloaded. At this point the diesel will be shut down and the hydro operator will resume control of system frequency.*

6 *As the turbine will be using less than the inflow, the headpond level will rise and return to normal ready for the next peak.*

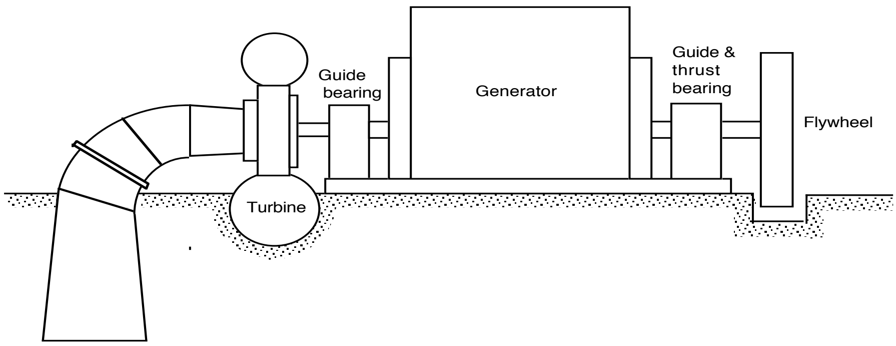
The above mode of operation is shown in the diagram below:



Either a differential pressure cell or a capacitor probe will be installed in the headpond to transmit the water level over a 4-20 mA circuit. Communication between the hydro station can be either by telephone, radio or by a low cost power line carrier system originally designed for rural telephone systems using the distribution lines.

Governing then has to be considered. The penstocks are fairly short but even so a flywheel is needed. This will be at the opposite end of the turbine from the turbine so that the turbine runner can be overhung from one end of the generator shaft and the flywheel from the other.

The machine is arranged as follows:



Note the simple shape of the draft tube and the two bearing arrangement

5 CONCLUSIONS

Schemes for remote areas must be designed to match the requirements of the power system. These requirements change from scheme to scheme and what suits one scheme may not be satisfactory for another. Each scheme has its own peculiar problems.

As with most problems in engineering, the designer must be certain that he really knows what he is trying to achieve and the relative importance of factors such as efficiency, governing, reliability, peaking capacity and storage for peaks.