Lagoon residential and recreational developments case study 1: Al Khaleej Village, Suudi Arabia

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Abstract

Half Moon Bay, approximately 20km long, and located 30km south of Al Khobar, is a natural tidal basin on the Arabian gulf coastline of Saudi Arabia (see figure 1). It is a popular resort in the region, with private and public beaches, and is used particularly at weekends for waterside recreation.

Saudi Hotels and Resort Areas Company (SHARACO) acquired a site on the west coastline of Half Moon Bay, for Al Khaleej Village, a waterside residential leisure, hotel and marina development.

The development was planned in five phases, and the first phase of housing and infrastructure was completed in 1991, not without difficulties, at first because the main contractor went into liquidation, and then as the works were being re-started, Kuwait was invaded and the Gulf War soon followed. The first phase was successful, but lessons were learned from it, and the master plan and subsequent phases were, as a result, substantially revised. A contract for the construction of a 750,000m\textsuperscript{2} inland tidal lagoon was let in February 1995, and was completed in April 1997. The construction of the second phase of housing and infrastructure development is currently underway.

Phase 1 Design

A first master plan was prepared by Sir William Halcrow and Partners Ltd, and
in 1986 Zuheir Al Fayez, a Saudi Arabian architectural practice, prepared a design for a first phase of 251 luxury housing units.

The first phase, of the planned five phase development, was concentrated within the south part of the site, around an attractive and sheltered bay, approximately 1km in diameter (see figure 2). The 251 housing units comprised four sizes of accommodation: one-bedroom apartments, two bedroom bungalows, and three and five bedroom villas. Recreational facilities were provided, including swimming pools, beach club, restaurant, a multi-purpose sports court, and a boat house with jetty leading to floating walkways and moorings. This initial small marina facility was intended primarily for boats up to 8m length, and for jet skis and pedalos.

The value of the first phase of construction was approximately SR150 million, or £25 million at current exchange rates.

**Interruption to the Phase 1 construction works**

The 21-month contract for the Phase 1 construction was awarded to Manufacturing and Building Company (MABCO), and work commenced on site in June 1988. The project came to a halt in December 1989 with the liquidation of MABCO, who had completed less than 40% of the work. During the run up to MABCO’s liquidation, co-ordination of works on site had been poor, with items of work being progressed out of sequence. The housing units were structurally complete, and yet most of the infrastructure, including a deep sewer, was still to be constructed. Individual villas had final fix M&E and internal doors, but not external doors and windows, a particular problem given the frequent spring sandstorms and high summer humidity.
Coastal Engineering and Marina Developments

In May 1990 Euro Happold were appointed as construction managers with a brief to achieve fast track completion of the project in one year.

When Kuwait was invaded, on 2nd August 1990, some package contracts had been let, some were being tendered, and some were still in the course of preparation. The run up to the Gulf War, and the Gulf War itself, seriously affected not only progress of work on the site, but also progress in letting contracts. There was a shortage of site labour as many expatriates fled the area, and contractors were concerned at the uncertainties of entering into contracts at that time. Material imports were seriously hampered, as insurance rates escalated and merchant shipping in the area was cut back. Not until some two months after the Gulf War was effective site progress on all contracts really achieved.

Substantial completion was achieved in November 1991. Bearing in mind the adverse conditions this was a satisfactory achievement, which was particularly assisted by SHARACO's commitment to maintain a full time presence on the site to ensure rapid decision making.

Lessons learned from the first phase of development

The Al Khaleej Village development sales office opened in October 1991 and by the summer of 1992 most of the properties had been sold.

The development was therefore clearly a success, but the pattern of demand was different from that which had been predicted by a market study carried out prior to the design of Phase 1. This study had suggested that, since Al Khaleej Village was a holiday and weekend resort, and would constitute a second home for owners of property, there would be a very slow demand if the development were to be sold. It concluded that rental may prove to be the only way of obtaining
Figure 3. Typical view of the Phase 1 development

As soon as sales started there was considerable interest in the larger units, and all of the five bedroom villas were sold within a matter of weeks. The three bedroom villas and two bedroom bungalows also proved a sales success, and within a few months all were sold, the first to sell generally being those closest to the sea. It took around two years to complete the sale of the one-bedroom apartments, in spite of the price being substantially lower than for other units.

Some of the recreation facilities have been successful, in particular the swimming, sports and boating facilities. The restaurant has been less successful, as the development does not create a large enough demand, and most occupants will cater for themselves as far as meals are concerned. There is, however, a good demand for drinks, snacks and takeaway food, especially at weekends.

Re-evaluation of the needs of the development

The success of the first phase had confirmed the market for waterside housing at Al Khaleej Village, but demonstrated that there is no sure demand for apartments, especially small ones. The marketing department of SHARACO therefore determined that future phases of housing should have a greater proportion of larger units, which as far as possible should have a direct frontage on to water.

The first master plan had envisaged later phases of houses or apartments, many with sea views, but mostly without direct access to water. A simple shaped inland lagoon had been included in this master plan, with provision for public walkways around its perimeter. Many interior residential lots had been planned, which would not have water frontage or water view. SHARACO decided that further development should be re-appraised, and appointed Buro Happold to revise the master plan.
Engineering and environmental evaluation of the lagoon

From the outset of revision of the master plan, it was assumed that a lagoon should be incorporated. The remaining undeveloped coastline of the site offered further opportunity for housing development with water views and water access. However, for the more marketable larger size houses, the undeveloped coastline could only accommodate a further 140 plots. If interior residential plots were unlikely to be successful, the development of the remainder of the site would be curtailed unless a lagoon was included. A simple form of lagoon would accommodate approximately 130 waterside residential lots, but this number could be increased significantly if the lagoon edge were to be lengthened by extensive indentation and embayment.

The site was flat, and the general level of the existing ground was around 700mm above mean sea level. This is too low for development, and fill would be required to raise ground levels sufficiently above mean sea level and ground water level. The excavation for the lagoon would provide a local source of material for ground raising, and at the same time it would enhance the value of the land formed.

The success of an artificially formed creek or lagoon system depends upon water quality and hydrodynamic performance. There are many examples of waterside projects that have been planned first and engineered second, and as a result have not performed well, and in some cases have serious problems of water quality or sedimentation. Revision of the master plan of this development was therefore not commenced until an evaluation of engineering and environmental factors had first been carried out.

Wind conditions

The winds in this part of the Arabian Gulf are predominantly north-westerly and are known locally as 'Shamal', the Arabic word for 'north'. Due to the fact that the general pattern of barometric pressure is similar both in summer and winter the Shamal persists throughout the year, and winds from the north west to north east quadrant occur for around 82% of the time. Winds from the southeast occur for about 11% of the time, and are generally associated with the autumn to spring seasons. Winds from the southwest are infrequent, generally of low intensity, and blow in an offshore direction.

Tides, Currents and Wave Conditions

The tides along the nearby Arabian Gulf Coastline, from Jubail to Dawhat Salwah, are semi-diurnal. However, the geography of Half Moon Bay considerably modifies the tides within its confines, and the tide differences between the Gulf of Bahrain and Half Moon Bay are considerable in both magnitude and time. Tidal monitoring shows a tidal range of approximately 300 mm at the site compared to a range of 1700 mm at Mina Salman in Bahrain. During the tidal monitoring,
high tide at the site occurred approximately 4 hours after high tide in Bahrain, and low tide occurred approximately 5 hours after low tide in Bahrain. Tidal monitoring indicates a 'mixed' tide with an intermediate high low water and low high water between the high and low tides.

The tidal velocities in Half Moon Bay are low and are generally less than 0.1m/s, which is a low velocity, insufficient to draw fine sands or medium to coarse silts into suspension. Wind induced currents in Half Moon Bay are of greater magnitude than tidal currents, and at force 5, the current half way down the bay will be of the order 0.23 m/s, sufficient to move fine particles from the sea bed.

Because of the shallow water depths and the small wind fetch, wave conditions in Half Moon Bay are mild. Wave conditions along the coastline of the Al Khaleej Village site are variable, because of the changing shoreline orientation, the varying exposure to wind, and the varying degree of protection afforded by offshore shallow water. The most affected part of the coastline of the Al Khaleej Village site is the north shore, which is exposed to the predominant north easterly and north-westerly winds which can generate waves over a fetch of over 11km. A caprock reef, at approximately 0.5m depth, extending eastward more than 2km from the shore protects the east shoreline.

For most of the time, wind conditions are such that wave heights throughout Half Moon Bay will be less than 0.25m. For extreme 1 in 50 year predicted wind conditions the calculated significant height of waves offshore, incident to the north shore, is 1.5m to 2m.

Waves incident to the coastline at an angle generate an along-shore current at the north coast of the site and influence sediment transport. These wave-induced currents have higher velocities than both the tidal and wind induced currents, particularly in very windy conditions.

**Bed sediments**

The sediments in Half Moon Bay in the vicinity of the Al Khaleej Village site are predominantly fine sands and silts, and derive from wind blown sand and dust from the desert. A calcarenite caprock reef of weakly cemented shells, predominantly grey silts, and fine sands, extends eastwards from the east shore of the site. Caprock occurs intermittently at the seabed surface along the shoreline.

**Littoral drift**

The offshore hydrodynamic environment in the vicinity of the Al Khaleej Village site is of low energy and littoral drift is limited in magnitude. The tidal current velocities are low, and insufficient to transport all but the finest sediments. Wind and wave generated currents predominate, and the littoral drift in Half Moon Bay is from north to south. Because of the low energy levels only the finer materials, such as fine sands and silts, are transported. These are deposited in quieter waters, and visual evidence for this exists at the southern end of the east coast of the site, where silts are being deposited.
New Layout of lagoon

Three major considerations were taken into account in the design of the lagoon:

- navigation
- water quality
- sedimentation

In considering navigation, the tidal and wave environment is fairly gentle, and there will be few problems with respect to flow velocities. Sometimes waves in tidal basins can cause problems for vessels but in general these do not cause problems in the lagoon, as the fetch is limited. Penetration of waves into the lagoon from Half Moon Bay is controlled by breakwaters and inlet channels.

Successful control of water quality usually depends on the periodic exchange of lagoon water with the main seawater. For single entrance harbours a complete exchange of water about every 10 days is usually adequate for proper control. However, water exchange does not always ensure good water quality, especially in back basins and dead ends. Elimination of direct sources of pollution, for example the direct deposition of sewage or garbage, is a significant factor in these cases and a specific policy should be formulated in this regard. Wind-driven surface currents may cause flotsam to accumulate at the ends of cul-de-sac channels facing prevailing winds, and it is necessary to carry out periodic cleaning of these areas.

At the Al Khaleej Village site, orientation is very important, as the winds are predominantly from northwest and northeast all the year round. Orientation of the lagoon to benefit from wind generated currents, and therefore circulation and mixing, significantly assists in the control of water quality.

We have recommended that no motor boats are allowed in the lagoon area, to avoid oil and oil related pollutants in this water body, and to allow the possibility of swimming. The remaining uses of the lagoon are limited to small sailing boats, rowing boats, pedalos, wind surfers, or similar craft.

Sedimentation aspects in lagoon design deserve special consideration because it may be possible to produce a design that reduces any possible siltation to a minimum, thereby saving a continual maintenance dredging problem and its associated cost. The location of principal inlet channel along the east coastline of the site has significant benefits in this respect because of the very low energy environment there, and the absence of significant quantities of sediment in the shallow water over the caprock reef.

Figure 4 illustrates the principles of lagoon form and orientation described above.

Ecology

Requirements for the conservation of marine life and breeding habitats of fish and shellfish should not be affected by schemes which are largely inland, and which involve little land reclamation.

As far as the Al Khaleej Village lagoon is concerned, there is no significant effect on existing breeding habitats of fish and shellfish from the dredging and
reclamation. Care is needed during dredging or excavation operations to limit turbidity from spreading long distances from the site, but the dredging or excavation is inland and is easier to control.

**Revision of the master plan**

Before revising the Master Plan, a series of objectives and development criteria were established. The most significant of these objectives and criteria are as follows:

- The assets of the site are its natural features of sea and coastline. These should be exploited to the full, as far as is compatible with the local ecosystem.
- The existing first phase should be fully integrated with the revised Master Plan so that the completed development has unity and continuity.
- The mix of house types and sizes should reflect the demand illustrated during sales of Phase 1. This indicated demand for a mix of seven-bedroom and four-bedroom villas and two-bedroom bungalows. There should be no apartments in Phase 2.
- Feedback from the residents of the first phase in relation to the villa designs and layouts indicated a preference for more privacy or larger plot sizes, as well as incorporation of maid’s accommodation in the villas.
- The village centre should be located nearer to the site entrance, so that private residential areas and public areas are segregated. The village centre should create a lively ‘heart’ of the development, with shops, cafes and indoor leisure facilities.
- There should be a balance between visitor and residential use of the site. Leisure and recreational facilities need to be provided for the residents, but some of these facilities will not be economically viable unless also open to visitors.
- A marina should be included, for both residents’ and public use, with access close to the village centre, thereby relating it to other leisure and recreational facilities.
- Later phases will include hotel or rental accommodation.

![Figure 4. Principles of lagoon form and orientation](image-url)
• The lagoon frontage should be maximised by the use of bays and inlets, with most houses on the lagoon having direct access to the water.
• The long axis of the lagoon should be oriented to take advantage of the prevailing wind direction. Prevailing winds should blow debris out of inlets, and not into them.
• The visual interest of the lagoon should be maximised through islands, bridges, and a variety of edge treatments.
• The development should be phased so that at the completion of each phase the development is an integrated whole, and not dependent on the next phase.
• The development phasing should be tailored to match available funding.
• Opportunities should be explored to enhance the quality of the natural environment, and increase bird and marine life populations. These include landscaping and the use of rock for shore protection and waterside edge treatments.
• The site has an attractive boundary at the coastline, but has a bleak boundary on the edge of the desert. This should be visually screened and softened by landscaping, which will also ameliorate the effects of wind blown sand.
• Road design should include landscape, curved alignments, roundabouts, and other devices that have a traffic calming effect.
• Water based outdoor leisure facilities could include fishing, boating, water slides and an 'aqua park'.
• Land based outdoor leisure facilities could include picnic areas, sports pitches, a small riding stables, a motor bike circuit, and a 'mini zoo'

Figure 5 shows the new master plan, and indicates the phasing of the development. The completed development will comprise more than 1000 residential units, most of which are houses. The general scope of phases 2, 3, 4 & 5 of the development is as follows:

• 760,000m² lagoon
• 154 seven-bedroom villas
• 273 four-bedroom villas
• 289 two-bedroom bungalows
• 59 two-bedroom apartments and 41 one-bedroom apartments in the village centre
• 54-room motel
• 50-room hotel
• 200-berth marina
• village shops
• sports and leisure facilities
• additional religious and administrative facilities

Existing and projected demand for marina facilities

A jetty and a floating pontoon marina facility for approximately 45 boats are incorporated into the completed first phase of the development, together with facilities for hiring pedalos and jet skis. A boathouse and slipway were also incorporated into the first phase. This boating and water sports facility has proved very popular, in particular the jet ski hire facility.
So far, the existing marina facility is not fully taken up, and it is currently felt that the full development, even when completed, will not generate demand for the existing facility together with the planned 200 berth second marina. Many of the existing residents do have boats, but these are mostly small light craft, which can be kept at the property. The most popular use of boats in the area is for fishing, and most of these craft are no longer than 5 metres. It is anticipated that demand will grow for berthing facilities as the development proceeds, and this demand will dictate the timing of the construction of the second marina. Once the village is built, it is expected that there will be public demand for mooring facilities at the site, and if this public demand is large, the proposed marina may end up being larger than 200-berths.

**Laboratory tidal model testing**

Hydraulic model tests of the proposed lagoon were undertaken in the hydraulics laboratory of the Department of Civil Engineering, Imperial College, London, during January to March 1993.
Model Test Objectives

The objectives of the physical model tests were to determine the interchange of water between the open sea and the lagoon and to measure tidal flow velocities. The results of the tests were also to be reviewed in relation to salinity and temperature changes in the lagoon, and the influence of winds acting on the surface of the lagoon water.

The Model

The physical model was constructed on the basis of a "distorted scale model", a concept normally applied to models of water bodies with large horizontal dimensions compared to the depths of water involved. In this case a horizontal scale of 1:500 and a vertical scale of 1:20 were selected. This results in a velocity scale of 1:4.47 (full scale velocities will be 4.47 times faster than those measured in the model), and a full-scale tidal period of 12 hours 26 minutes being simulated in 6 minutes 40 seconds in the model. The test series were based on a representative tide of 0.3m range (low to high) and 12 hours 26 minutes period - based on the tidal data available, with a mean water depth of 1.7m.

The model was constructed in a tank 5m x 3.5m in plan with a flow delivery system controlled by valves from a 'constant head' laboratory supply. This allowed tidal level variations at the South and North inlet/outlet channels to be controlled and repeated in a continuous series to simulate several days of tidal variations at full scale. The boundaries of the lagoon, and the islands, were formed from large impervious styrofoam sheets cut accurately to the plan layout.

The degree of penetration of "new" water, i.e. water from the open sea within Half Moon Bay, was determined by timed video-tape recordings using a video-camera suspended above the model, with dye injection into the incoming flow over the first low water to high water half tidal cycle. The camera provided a view of the entire model and recordings normally lasted for some 40 minutes for each test - continuous tidal variation equivalent to three days at full scale.

The flow velocities in the model are small and were therefore determined by tracking the movement of floats within the lagoon, again by videotaping over a series of tidal cycles. The accuracy of float displacement and timing were such as to provide reliable measurements of flow velocities with the model.

Results

Preliminary tests on the original geometry of the lagoon showed that the orientation of the South channel as it entered the lagoon was not optimal - too much of the incoming flow was caused to circulate in bay 9 (see figure 7).

The geometry of the channel was therefore modified on both sides as it entered the lagoon proper, to change the main direction of the flow towards the geometrical centre of the lagoon while maintaining adequate circulation in bay 9.

Five major test series were then defined on the basis of the observations of the performance of modified geometry, as follows:
Figure 6. Hydraulic test model

Test Series 1

The first modification of geometry (south inlet) significantly improved the propagation of tidal flow into the centre of the lagoon while maintaining adequate circulation in bay 9 - confirming the validity of the modifications. The degree of penetration into bays 4, 5 and 6 is only partial and hence less than satisfactory.

Test Series 2

Opening of the north inlet, with a weir across it at an elevation of mean sea level so that only the top half of a tidal cycle flows into and out of the lagoon, significantly improves the conditions in bay 5. It results in a zone of convergence of flow entering via the south inlet and flow entering the north inlet. However, the penetration into bays 4 and 6 is still incomplete.

Test Series 3

Unrestricted opening of the north inlet increased the flow and exchange in bay 5, as expected. It causes the convergence zone to move southwards further into the lagoon but does not significantly improve conditions in Bays 4 and 6.

The series illustrated the need to modify the plan layout near the North Inlet and showed the potential for improvement by changes to the geometry of the island in bay 5 to encourage the flow on both flood and ebb tides.

Test Series 4

The second modification of geometry was introduced. The coastline layout in bay 5 was modified together with the geometry of the island in that bay. Additionally a channel was introduced to link bay 4 to bay 5 in order to improve penetration to the former. Bay 6 was, however, still not adequately penetrated by 'new water'.
The third modification of geometry was introduced. Based on Test Series 4, a channel linking bays 5 and 6 was introduced, together with a further refinement of the geometry of the island in Bay 5 in anticipation of the need to induce flow via the new N.E. channel.

The final layout which evolved through the model test programme demonstrated clearly that adequate mixing/penetration would be achieved in six tides (approximately a three-day tidal series). This time scale is significantly more demanding than criteria adopted in similar developments (which have proved successful in performance) in which six-days and even ten-days are used as the time-scale.
The velocity directions and magnitudes measured via float tracking were recorded and plotted. The velocities are low, as expected from calculations on volume change given the small tide range in Half Moon Bay. The inlet/outlet channel cross-sections have been designed with cross-sections so as to control velocities within them to prevent sedimentation and avoid scour.

**Wind induced flows**

When winds blow over an open water surface, the shear stresses imposed on that surface induce a current in the water, which at the surface is flowing in the same direction as the wind. The magnitude of this wind-induced current is, typically, 3% of the wind speed.

At Half Moon Bay - based on wind speeds measured at Dhahran - winds between 0 and 5 m/s blow from the north to northwest sector for some 40% of the time, and between 5 and 10 m/s for some 23% of the time. Therefore water surface currents of 7.5 cm/s and 22.5 cm/s would be induced for a similar percentage of time (taking the average wind speeds in each case).

Comparison with flood and ebb tidally induced velocity shows that wind-induced flows will dominate over a large area of the lagoon - especially towards the North end and in the bays. These flows will therefore create a surface flow towards the south of the lagoon with beneficial effects on mixing and circulation.
The wind-induced current at the water surface reduces rapidly with depth so that the total water volume flows are small. However, within a bay the southerly wind-induced surface flow will be balanced by a return flow lower down in the water column.

Taking a surface water velocity of 3% of the wind speed and assuming the velocity profile in the vertical decays to 10% of the surface velocity at 25 cm below the free surface, then the discharge per unit width of flow is given by

\[ q = \int_0^{0.25} V \, dy, \quad \text{where} \quad V = a \exp(-by) \]

where \( y \) is measured positive downwards from the water surface, \( b = 10 \) and the water depth, \( d = 1.75 \text{m} \).

With a wind speed of 5 m/s, \( q = 0.015 \text{ m}^2/\text{s}/\text{per metre width of flow} \), which over a 125m wide bay-mouth gives a total discharge of 1.88 m3/s.

To compare this with the discharge induced by tidal motion, we take a maximum rate of tidal rise (or fall) as 0.1m per hour. Thus a bay area of say 125m x 350m gives a discharge of

\[ \frac{0.1 \times 125 \times 350}{3600} = 1.21 \text{ m}^3/\text{s} \]

Therefore, fully established wind-induced currents result in discharges that are of a similar order to tide-induced discharges and therefore add significantly to the circulation and mixing processes within the lagoon.

**Waves**

Using a fetch of 2000m, winds of 5 m/s and 10 m/s will generate waves within the lagoon, of 0.15m and 0.3m significant wave heights respectively, with corresponding wave periods of 1.0 and 1.5 seconds. The lengths of these waves will be between 1.5 and 3.5m. For the 10 m/s winds the wave agitation will be marginally felt by sediment at the bed of the lagoon, but insufficient to cause sediment transport. However, this degree of wave agitation will enhance the mixing of the water within the lagoon, adding to the tide and wind induced flows to further improve water quality.

**Salinity and temperature**

Given the good tidal and wind-induced mixing and water exchange within a period of approximately three days, there will not be significant variations in salinity and temperature between the lagoon and the open waters of Half Moon Bay. Water within the lagoon will mix with incoming flows from Half Moon
Bay and on ebb tides will be moved out into the Bay itself with further mixing and dispersion offshore. This degree of interchange will maintain near parity in salinity and temperature between lagoon and Bay water.

**Water quality**

**Water quality in Half Moon Bay**

In June 1994, Al Hoty Stanger carried out water quality analysis on 20 samples of sea water in Half Moon Bay, taken from 4 transects adjacent to the Al Khaleej Village site. The average value of faecal coliform count was 41 per 100ml. The results of water quality analysis on 4 samples of sea water in Half Moon Bay, taken at the same time from a transect at the northern end of Half Moon Bay gave an average value of faecal coliform count of 38 per 100ml. For comparison, 4 samples of sea water were taken at the same time from a transect within a trapped lagoon adjacent to the Entertainment Centre at the north of Half Moon Bay, and water quality analysis showed an average value of faecal coliform count of 41 per 100ml.

For the European Standards for bathing beaches to be met, the faecal coliform count must fall below the following levels:

- **Guideline level**: 100 per 100ml (with 80% of all samples falling below this level)
- **Mandatory level**: 2000 per 100ml (with 95% of all samples falling below this level)

**Water quality in the lagoon**

Faecal coliform counts carried out on samples taken from transects adjacent to the Al Khaleej Village site show that the levels are within the limits of European Guidelines for bathing beaches.

SHARACO opted to provide, as far as reasonably practicable, beaches for bathing along the perimeter of the lagoon. Therefore maintenance of good water quality in the lagoon is of paramount importance.

The tidal model testing has shown that there is good penetration of tidal flushing to all parts of the lagoon. Regular mixing of water will additionally enhance the tidal exchange by wind effects.

The shape and orientation of the lagoon and the location of the inlets have from the outset of planning been determined to gain maximum benefit from tidal and wind effects.

The quality of water in the Al Khaleej Lagoon will therefore be essentially the same as that within Half Moon Bay itself, provided there are no significant inputs of pollutants into the lagoon from the occupants of the Village.

Approximately 500 houses will eventually be developed around the lagoon. The activity of the occupants of these houses, and the drainage to these houses, provide the only risk of input of pollution into the lagoon. Therefore,
maintenance of water quality within the lagoon will be a matter of operations and maintenance of the development, and the controls placed on the use of the lagoon and its adjacent land. Accidental pollution occurrences will be catered for by the daily tidal exchange of around 30% of the volume of lagoon water.

Measures to deal with possible pollutant inputs

A number of measures to deal with the risks of pollutant input into the lagoon were agreed with SHARACO, as follows:

- Septic tanks should not be used.
- High quality of sewerage pipework should be specified.
- No stormwater is to be discharged from roads or public hardscape areas into the lagoon without the use of sediment traps and petrol interceptors.
- Garden landscape is to be designed not to run-off directly into the lagoon.
- Clean lagoon and edges of debris on a daily basis. Ensure that a maintenance access corridor is available at all times at beaches.
- Encourage residents to prevent litter and waste from entering the lagoon, by provision of waste bins, well designed notices and good public relations techniques.
- Prohibit barbecue equipment and other potential pollutants from the beaches.
- Prohibit the use of motorised craft on the lagoon, other than vessels under the control of SHARACO, such as maintenance craft or a ferry.
- Provide buoys at beaches to separate bathing areas from leisure and sports craft, and advise residents against swimming outside buoy marked areas.
- At 3 monthly intervals, and additionally if there is reason to suspect that pollution has entered the lagoon: monitor water quality, on 5 samples taken at each of 5 predetermined locations within the lagoon, and on 5 samples taken at each of 2 predetermined locations in Half Moon Bay.

The variety of lagoon edge treatments

A number of lagoon edge treatments are employed, to suit the particular local requirements, and to provide variety and interest to the lagoon.

SHARACO felt that residents would prefer as far as possible to have their own personal access to a sandy beach at the lagoon side of their properties. Therefore sandy beaches are provided over much of the lagoon perimeter.

The general reclamation and building level is approximately 2 metres above mean sea level. As the tidal range is small, a lower lagoon edge level has been used, providing a waterside patio or walkway 0.5 metres above mean sea level. This edge may very occasionally flood during surge tides, but sea levels in Half Moon Bay have in the last 5 years have not exceeded this edge level more than twice a year.

At channels it is important to form and maintain a waterway which is at its full depth across as much of its width as practicable. This applies at the inlet channels and to the channels at islands. A stone armoured revetment is used at these locations, to provide adequate cross section of channel, using a natural
material sympathetic to the marine environment, which will encourage the development of marine life.

At lagoon edges which are too vulnerable to scour to allow a beach, a stone armoured revetment is used, with a 3.5 metre wide shelf providing safe shallow water at the edge.

The east side of the lagoon is to be developed in later phases, and in order to provide flexibility and not to invest too much too early there, the edges are to be left largely unfinished in the early stages.

Stone armoured breakwaters extending into Half Moon Bay are provided at the north inlet to a water depth of 2 metres. One arm of the breakwater will provide access to the second marina, which is to be built in a later phase.

Operations and maintenance considerations

All buildings and constructions require maintenance, and the Al Khaleej Lagoon is no exception. Its operations and maintenance requirements are, of course, particular to maritime constructions and to the use to which the lagoon and its environs will be put.

The purposes of operations and maintenance of the Al Khaleej Lagoon are:

- Ensuring safety of the Village occupants and users
- Maintaining acceptable water quality
- Ensuring a tidy and pleasant appearance
- Ensuring continued integrity of the construction

Operations and maintenance in respect of water quality are covered in the water quality section above.

Maintenance dredging

Long term silt maintenance dredging will be required. However, siltation is not a major problem at the Al Khaleej Lagoon, because seabed sediments are primarily sandy, and sediment loads are not high because of the generally low hydrodynamic energy within Half Moon Bay. Some siltation will occur in areas where water velocities throttle down, such as in the vicinity of entrance channels. At most, maintenance will be required every few years, and quantities can easily be handled by small shallow draft craft.

Navigational access

Unauthorised craft entry into the lagoon is deterred by three obstructions at each inlet channel. Roped buoys provide the first line of clearly visible obstruction. Two rows of booms then serve the dual purpose of preventing access and of providing a safety barrier against an inexperienced or very young bather being carried out into Half Moon Bay by the tide. The booms will also trap larger items of debris.
Conclusions

The design of the Al Khaleej Village lagoon has necessitated a strong interaction between engineering and planning. It was recognised at an early stage that hydrodynamics, phasing of construction, water quality and so on must be taken into account in the planning of the project. By taking these factors into account at the outset, the design has benefited, and engineering considerations have assisted in developing the design rather than solving problems arising from planning.

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